HOW TO VIEW THIS MONTH'S **LUNAR ECLIPSE** p. 46

MAY 2021

# Astronomy®

The world's best-selling astronomy magazine

## HOW WE CAN VISIT ANOTHER STAR

Breakthrough Starshot plans robotic craft to Proxima Centauri p. 16

Explore gems of the deep southern sky p. 48

www.Astronomy.com

**BONUS ONLINE CONTENT CODE p. 4**

Vol. 49 • Issue 5

**» PLUS**

**See Apollo 14 in 3D** p. 40

Celestron's StarSense scope reviewed p. 54

Bob Berman on astrophysical food fights p. 13

EXCLUSIVELY FROM *ASTRONOMY* MAGAZINE

# MOON GLOBE

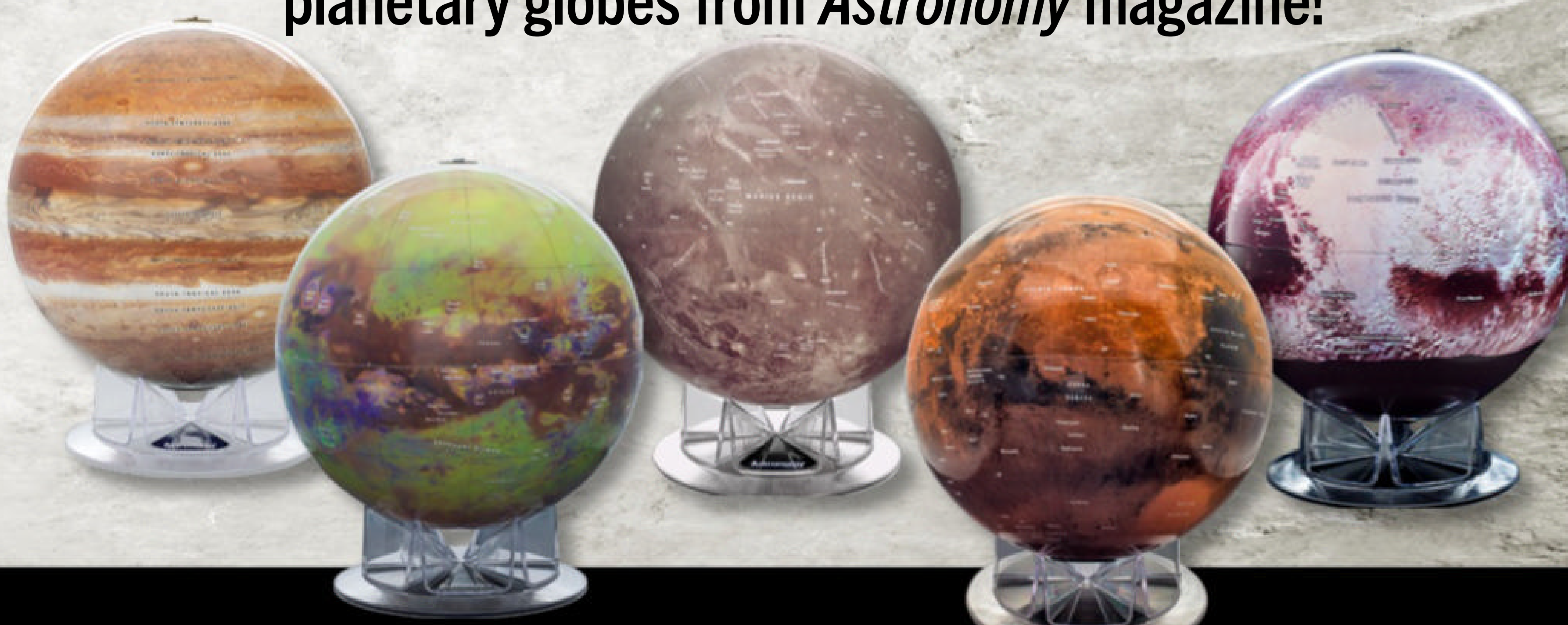
Explore our closest celestial body with the most complete 12” desktop Moon globe, featuring richly detailed images.

**NEW!**

## This all-new and up-to-date globe offers:

- Images from the **Lunar Reconnaissance Orbiter mission** and maps from the USGS.
- **1,473 lunar features** including 20 of the top Apollo and spacecraft landing sites.
- Custom-produced, injection-molded globe with a single seam and a clear acrylic display base.

**Don’t miss out on the extensive assortment of exclusive planetary globes from *Astronomy* magazine!**



**Shop Now:**

**MyScienceShop.com/ASYGlobes**

**Sales tax where applicable.**

P38577

**Online Content Code: ASY2105**
Enter this code at: **www.astronomy.com/code**
to gain access to web-exclusive content


# CONTENTS

MAY 2021
VOL. 49, NO. 5

ON THE COVER
The Breakthrough Starshot project aims to send tiny robotic craft to nearby star Proxima Centauri.
RON MILLER FOR *ASTRONOMY*

## FEATURES



## COLUMNS



## IN EVERY ISSUE



**ONLINE FAVORITES**
Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.

**My Science Shop**
Perfect gifts for your favorite science geeks.

**News**
The latest updates from the science and the hobby.

**Sky This Week**
A daily digest of celestial events.

**Ask Astro Archives**
Answers to all your cosmic questions.

*Astronomy* (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Media Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, PO Box 8520, Big Sandy, TX 75755. Canada Publication Mail Agreement #40010760.

# Can we travel to the stars?

In the 1902 short film *A Trip to the Moon*, the poor Man in the Moon takes spacecraft to the eye. WIKIMEDIA

As long as our ancestors have looked skyward, humans have dreamed about traveling to the stars. For hundreds of years, as the notion of what stars really are began to crystallize, the dreams persisted, eventually making their way into our literature and film. A century and a half ago, Jules Verne penned *From the Earth to the Moon*; some 30 years later, the French filmmaker Georges Méliès created the wonderful short *A Trip to the Moon*, in which poor Mr. Moon gets struck in the eye with a projectile.

In the wake of the Apollo Moon missions, now half a century ago, would-be astronauts have toyed with not only returning to our close celestial neighbor, or pushing on to Mars, but also of traveling out to other star systems. Could we really travel to the stars?

As dreams of seeing other celestial worlds have grown, so has the realization of the enormity of the cosmos, even the staggering scale of the distances to just the nearest stars to our Sun. Imagine the cosmic distance scale of 1 astronomical unit, the Earth-Sun distance, as 1 centimeter. On that scale, humans have traveled only a tiny, almost invisible distance. The edge of our solar system, the inner edge of the Oort Cloud, would be about 10 football fields away. And that's only about a quarter of the way to the nearest star, Proxima Centauri, some 4.2 light-years off.

The trouble with large distances is that regardless of how technology greatly improves in the future, physics is physics. Photons can travel enormously large distances because they are massless. But anything with mass, including humans inside some craft, would take an incredible amount of energy to send on such long-distance trips. The best engines we can envision now might take 75,000 years or so to traverse the distance to Proxima Centauri, and that is a very long time, folks.

But perhaps we could instead send tiny robots to the nearest stars. In this month's story on Breakthrough Starshot, Associate Editor Jake Parks explores what Avi Loeb and his collaborators are attempting, the first micro-robotic mission to the stars.

Stay tuned. Maybe we'll make it to the stars someday — via our electronics — despite the daunting challenges.

Yours truly,

David J. Eicher

*Follow the Dave's Universe blog:* **www.Astronomy.com/davesuniverse**
*Follow Dave Eicher on Twitter:* **@deicherstar**

FOLLOW *ASTRONOMY*

facebook.com/AstronomyMagazine
twitter.com/AstronomyMag
youtube.com/user/AstronomyMagazine
instagram.com/astronomy.magazine

Astronomy

**Editor** David J. Eicher
**Design Director** LuAnn Williams Belter

EDITORIAL
**Senior Editor** Mark Zastrow
**Production Editor** Elisa R. Neckar
**Senior Associate Editor** Alison Klesman
**Associate Editor** Jake Parks
**Associate Editor** Caitlyn Buongiorno
**Editorial Assistant** Hailey McLaughlin

ART
**Contributing Design Director** Kelly Katlaps
**Illustrator** Roen Kelly
**Production Specialist** Jodi Jeranek

CONTRIBUTING EDITORS
Michael E. Bakich, Bob Berman, Adam Block, Glenn F. Chaple Jr., Martin George, Tony Hallas, Phil Harrington, Korey Haynes, Jeff Hester, Alister Ling, Stephen James O'Meara, Martin Ratcliffe, Raymond Shubinski, Richard Talcott

EDITORIAL ADVISORY BOARD
Buzz Aldrin, Marcia Bartusiak, Jim Bell, Timothy Ferris, Alex Filippenko, Adam Frank, John S. Gallagher III, Daniel W. E. Green, William K. Hartmann, Paul Hodge, Edward Kolb, Stephen P. Maran, Brian May, S. Alan Stern, James Trefil

Kalmbach Media
**Chief Executive Officer** Dan Hickey
**Senior Vice President, Finance** Christine Metcalf
**Senior Vice President, Consumer Marketing** Nicole McGuire
**Vice President, Content** Stephen C. George
**Vice President, Operations** Brian J. Schmidt
**Vice President, Human Resources** Sarah A. Horner
**Senior Director, Advertising Sales and Events** David T. Sherman
**Advertising Sales Director** Scott Redmond
**Circulation Director** Liz Runyon
**Director of Digital Strategy** Angela Cotey
**Director of Design & Production** Michael Soliday
**Retention Manager** Kathy Steele
**Single Copy Specialist** Kim Redmond

ADVERTISING DEPARTMENT
**Phone** (888) 558-1544
**Ad Production** AdServices@Kalmbach.com
Dina Johnston, djohnston@kalmbach.com

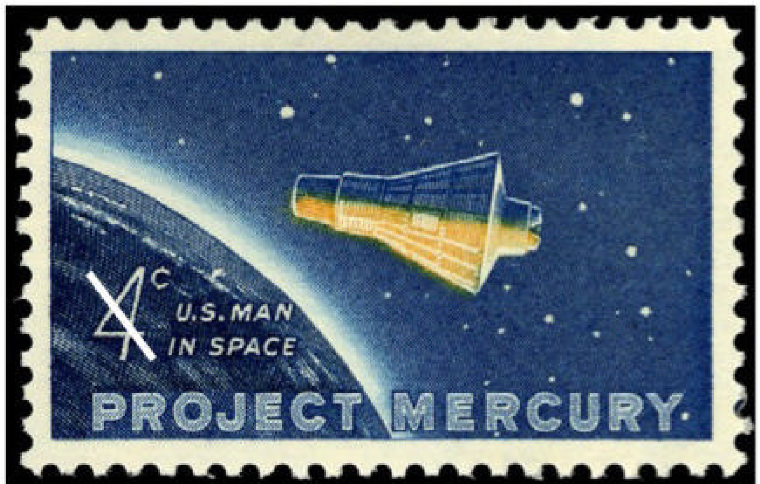
RETAIL TRADE ORDERS AND INQUIRIES
Selling *Astronomy* magazine or products in your store:
**Phone** (800) 558-1544
**Outside U.S. and Canada** (262) 796-8776, ext. 818
**Fax** (262) 798-6592
**Email** tss@kalmbach.com
**Website** www.Retailers.Kalmbach.com

CUSTOMER SALES AND SERVICE
**Phone** (877) 246-4835
**Outside U.S. and Canada** (903) 636-1125
**Customer Service** customerservice@AstronomyMagazine.info

CONTACT US
**Ad Sales** adsales@astronomy.com
**Ask Astro** askastro@astronomy.com
**Books** books@astronomy.com
**Letters** letters@astronomy.com
**Products** products@astronomy.com
**Reader Gallery** readergallery@astronomy.com
**Editorial Phone** (262) 796-8776

For reprints, licensing, and permissions:
PARS International at www.parsintl.com

## Splash down stamp




The 1962 Project Mercury postal stamp. SMITHSONIAN NATIONAL POSTAL MUSEUM

Katrin Raynor-Evans' November 2020 article, "Collect the cosmos in stamps," reminded me of something I found a few years ago while cleaning out my father's garage. I took home a toolchest and was looking through it when I found an envelope. The stamp on the envelope cost $0.04 and was made for the Project Mercury program going on at that time. Of interest is the postmark canceling the stamp: The postmark is for the Cape Canaveral post office, but Canaveral didn't have a post office at that time. This is a special postmark issued by the United States Postal Service to mark the successful splash landing. My father says he has no idea how he ended up with this envelope and thinks it might have been in the toolchest when he got it from a friend.
**—Dan "Santa" Stone,** Belen, NM

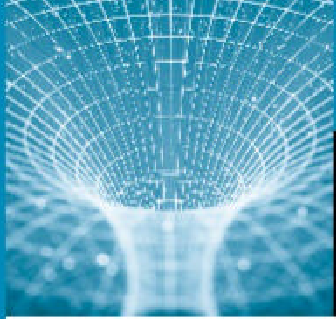
## Cover to cover

I just finished reading the January 2021 issue of *Astronomy* cover to cover. What a fantastic idea to do a complete issue on cosmology! The articles, written by scientists active in the field and contributing editors, surveyed the topic very nicely. Although ambitious, I think it would be great to do other surveys in the future. **—Richard Brady,** Brick, NJ

## The importance of Roen Kelly

I would like to propose a frightening question: What if all of Roen Kelly's illustrations in the January issue disappeared? I counted 32 of them! I have taught high school science for 44 years, and though we embrace *Astronomy* magazine's well-written articles and salivate over the gorgeous photographs, it takes an illustrator to help us make sense of a multitude of concepts. I praise Roen for helping us visualize what the writers are talking about. They are integral to the magazine's high standard of quality. **—James McLeod,** Charlotte, NC

*We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to* **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*





SNAPSHOT

# WHEN WORLDS COLLIDE

## To understand bursts of star formation, astronomers target galaxy mergers.

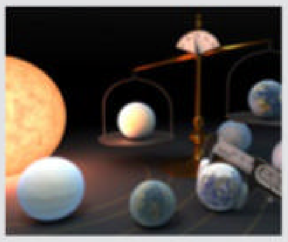
The universe is a sea of seemingly empty space. Yet, despite its vastness, galaxies still frequently slam into each other in gravitational death dances.

The Hubble Space Telescope captured six such merging systems in these images. But galactic collisions don't just make for pretty pictures; researchers also use them to understand the evolution of galaxies throughout the universe.

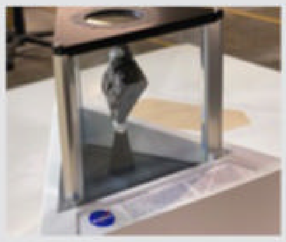
When galaxies combine, their shapes are distorted and their contents rearranged. This forges a new generation of stars in an event called a starburst. And the star clusters created in these mash-ups become long-lasting witnesses to their galaxies' dramatic transformations. Researchers used Hubble to study the ages, masses, and amount of dust within these galaxies' new star clusters as part of a survey called the Hubble imaging Probe of Extreme Environments and Clusters. The survey collects ultraviolet, visible, and near-infrared light to help scientists determine how mergers impact the rate of star formation in galaxies.

One day, our own Milky Way Galaxy will merge with our neighbor, the Andromeda Galaxy. The collision won't occur for another 4.5 billion years, but by studying distant mergers, astronomers can better understand what will happen to our home far in the future. —HAILEY ROSE MCLAUGHLIN

## HOT BYTES



**PLANETARY SEPTUPLETS**
The TRAPPIST-1 system's seven rocky exoplanets are all roughly the same density — about 8 percent less dense than our own planet — suggesting their compositions are similar to each other but notably different from Earth's.



**PRESIDENTIAL PAPERWEIGHT**
A rock chipped off a boulder on the Moon by Apollo 17 astronauts is now on display in the Oval Office of the White House. NASA supplied the lunar sample at the Biden administration's request.

**QUICK-FORMING QUASAR**
A newly discovered galaxy houses the oldest known quasar, which is an actively feeding supermassive black hole. J0313–1806 contains a central black hole 1.6 billion times the mass of the Sun that formed just 670 million years after the Big Bang.

TOP, CLOCKWISE FROM UPPER LEFT: ESA/HUBBLE, NASA; NASA, ESA, THE HUBBLE HERITAGE TEAM (STSCI/AURA)-ESA/HUBBLE COLLABORATION AND A. EVANS (UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE/NRAO/STONY BROOK UNIVERSITY); ESA/HUBBLE & NASA, A. ADAMO; ESA/HUBBLE & NASA, A. ADAMO ET AL.; ESA/HUBBLE & NASA, A. ADAMO ET AL.; NASA, ESA, THE HUBBLE HERITAGE TEAM (STSCI/AURA)-ESA/HUBBLE COLLABORATION AND A. EVANS (UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE/NRAO/STONY BROOK UNIVERSITY). BOTTOM FROM LEFT: NASA/JPL-CALTECH; NASA; ESO/M KORNMESSER

# SUCCESS! NASA safely lands Perseverance on Mars

## The most sophisticated martian rover ever built is ready to explore the Red Planet.

**CAUGHT ON CAMERA.** Perseverance's descent cameras captured its thrilling landing sequence: its parachutes opening, its heat shield falling away, and finally, it hovering over the ground and being winched to the surface — prompting celebrations at NASA's Jet Propulsion Laboratory. BOTTOM RIGHT: NASA/BILL INGALLS. ALL OTHERS NASA/JPL-CALTECH

NASA's Perseverance rover is safe and sound on Mars.

At approximately 3:55 P.M. EST on Thursday, Feb. 18, 2021, mission control at NASA's Jet Propulsion Lab in Pasadena, California, erupted in jubilation upon receiving confirmation that their latest interplanetary rover made it to the martian surface unscathed, completing a seven-month, 293-million-mile (471 million kilometers) journey.

NASA couldn't have asked for a better landing. In a post-landing press conference, Thomas Zurbuchen, head of NASA's science missions, said, "Every time we do a launch or do a landing, we get two plans. One plan is the one we want to do. And then there's that second plan, which is right here — that's the contingency plan."

Zurbuchen then stood up, lifted a thin stack of lightly leafed-through papers into the air, and triumphantly tore them apart while calling out, "Here's for the contingency plan!"

### NAILING THE LANDING

Perseverance began its landing ordeal — the so-called "seven minutes of terror" — by entering the Red Planet's atmosphere at a blistering 12,000 mph (19,300 km/h), protected by a robust heat shield. But because Mars' atmosphere is only about 1 percent as dense as Earth's, its ability to slow incoming spacecraft is limited.

That's why Perseverance was equipped with a massive supersonic parachute, which it deployed while still traveling at twice the speed of sound. This further slowed the craft's descent, allowing the vehicle to use its brand-new Terrain Relative Navigation system, which compared real-time images to a pre-stored map of the landing area to help the rover avoid hazardous terrain.

After jettisoning its parachute roughly 1 mile (1.6 km) above the

surface, the craft was still traveling at some 160 mph (250 km/h). That's when the rocket-powered descent vehicle took over, firing its multiple thrusters to further slow Perseverance's descent and direct it to a safe landing site.

Finally, the craft carried out its famed Skycrane maneuver, first used by NASA's Curiosity rover in 2012. While hovering at about 70 feet (21 meters) above the surface, a winch gently lowered Perseverance via tethers to the floor of Jezero Crater.

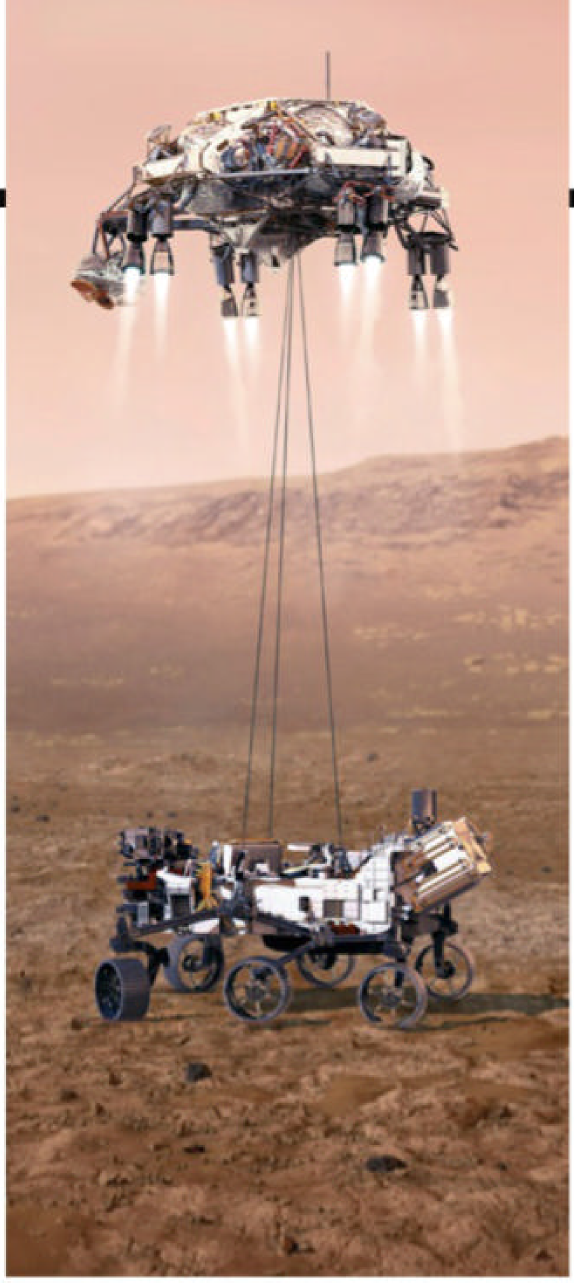
The entire maneuver was captured by a set of off-the-shelf cameras mounted to the rover and its descent stage, resulting in spectacular footage — the first ever of a spacecraft landing on another planet. Perseverance is also fitted with a microphone that captured the sound of a gust of martian wind in the first true audio recording from another planet.

### PERCY'S NEXT JOURNEY

With a safe touchdown marked off the rover's to-do list, Perseverance will next perform a number of tests to ensure everything is working properly before kicking off its mission in earnest.

Within the next few months, Perseverance is expected to drop off its tag-along experimental helicopter drone, Ingenuity, before rolling away

**NEW DIGS.** This color version of the first image sent back from NASA's Perseverance rover upon safely landing on Mars was taken by one of the rover's Hazard Avoidance Cameras. NASA/JPL-CALTECH



**DRAMATIC ENTRANCE.** Using a maneuver first tested with Curiosity, Perseverance touches down on Mars in this illustration. NASA/JPL-CALTECH

to a safe viewing distance while the rotorcraft carries out a series of tests.

From there, Perseverance will continue with its primary mission — investigating areas of interest throughout Jezero Crater, a fascinating ancient lakebed that may have once served as an abode for martian life. There, the rover will attempt to characterize the site's past geology and search for signs of ancient martian life.

If Perseverance finds a particularly intriguing target, it will use its coring drill to collect and store a sample from the site. Periodically, it will deposit its samples at designated cache depots for a future sample-return mission to retrieve and return to Earth.

As NASA's head of planetary science, Lori Glaze, put it, "Now that we're on the ground … the fun really starts."

— JAKE PARKS

**The red-and-white markings on Perseverance's parachutes carried two hidden messages written in binary code: the Jet Propulsion Laboratory's unofficial motto, "Dare mighty things," and the latitude and longitude coordinates for JPL's Pasadena campus.**

## QUICK TAKES

### EVER-CLEAR SKIES

Hubble Space Telescope observations of the hot Jupiter WASP-62b revealed that it has no observable clouds or haze in its atmosphere. It's the second known exoplanet with completely clear skies.

### GALACTIC GEYSER

Astronomers have found that the core of galaxy ESO 253–3 regularly erupts in a flare about every 114 days. This reliable nature allowed scientists to plan ahead and observe several flares in 2020 with multiple telescopes, including NASA's Neil Gehrels Swift Observatory.

### UNEXPECTED LIGHT

The New Horizons probe, currently exploring the Kuiper Belt, has found that empty space is not as dark as expected. The extra light could mean there are more faint galaxies than theory predicts, creating a brighter background glow.

### FALSE-PHINE?

The debate over a claimed detection of phosphine in Venus' atmosphere — a potential indicator of microbial life — continues as a new study suggests the signal can instead be explained by sulfur dioxide.

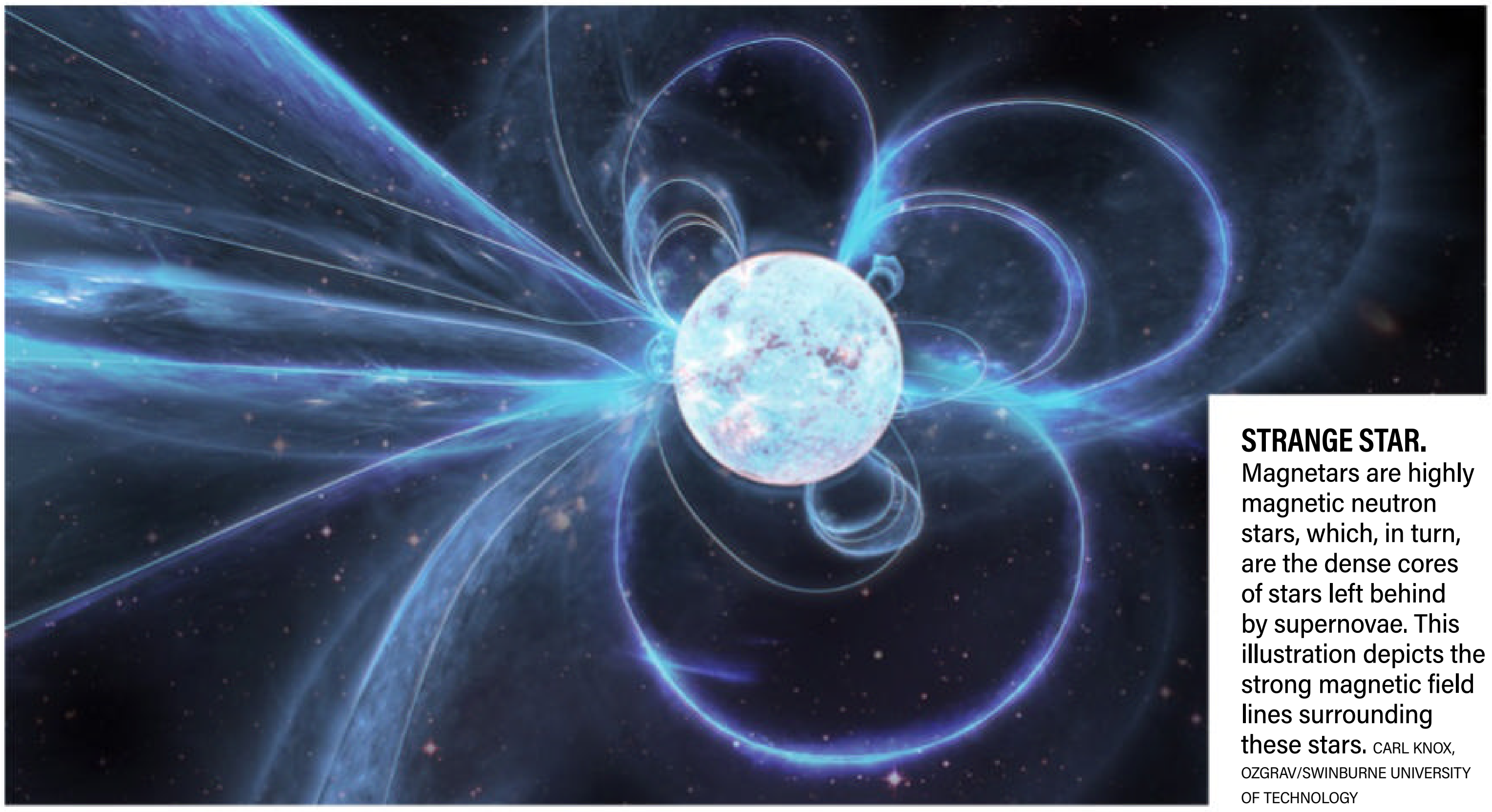
### SNUFFED OUT

Astronomers found a distant galaxy that's ejecting nearly half its available star-forming gas — roughly 10,000 Suns' worth per year. They think the gas leak was triggered by a recent collision with another galaxy.

### LUNAR HERITAGE

On Dec. 31, 2020, the U.S. enacted legislation to protect "lunar heritage sites," such as the Apollo landing sites. The One Small Step to Protect Human Heritage in Space Act now requires NASA and any organization it partners with to avoid disturbing these areas.

— MARK ZASTROW, J.P.



**STRANGE STAR.** Magnetars are highly magnetic neutron stars, which, in turn, are the dense cores of stars left behind by supernovae. This illustration depicts the strong magnetic field lines surrounding these stars. CARL KNOX, OZGRAV/SWINBURNE UNIVERSITY OF TECHNOLOGY

**4**

**The distance, in inches (10 cm), that Mars wobbles around its spin axis every 207 days, making it the solar system's second known body, after Earth, with a Chandler wobble.**

# Astronomers find the youngest, fastest-spinning magnetar yet

Fresh observations are shedding more light on the newest member of the bizarre class of stars called magnetars — and astronomers are running out of superlatives to describe it.

Neutron stars are ultradense objects — second only to black holes — that compress more than a Sun's worth of mass into a sphere only about as wide as Manhattan. And magnetars are a rare subset of neutron stars that sport the universe's most powerful magnetic fields — roughly 1 million billion times stronger than that of Earth.

However, astronomers have only identified 31 magnetars out of the 3,000 or so known neutron stars. After the discovery of the newest member, Swift J1818.0-1607 (J1818 for short), by NASA's Neil Gehrels Swift Observatory in March of last year, researchers were eager to observe it further. So, later that year, they turned NASA's Chandra X-ray Observatory its way.

They found that J1818 is even more special than previously thought. With an estimated age of merely 500 years, J1818 is the youngest known magnetar. The baby star whirls around once every 1.4 seconds, also making it the fastest-spinning magnetar yet found. Their findings were published November 2020 in *The Astrophysics Journal Letters*.

And J1818 wasn't done surprising astronomers. While magnetars typically emit lots of X-rays and gamma rays, J1818 was also observed giving off regular radio pulses. Only five magnetars, including J1818, have been seen exhibiting such radio-loud behavior, which resembles that of pulsars — fast-spinning neutron stars that emit powerful beams of radio waves from their poles. Curiously, J1818 initially appeared more pulsarlike than the four other known radio-loud magnetars. Those objects emit pulses that are consistently bright across the radio-wave spectrum, whereas a typical pulsar — and J1818 — is brighter at longer wavelengths.

However, in a second paper, published March 2021 in *Monthly Notices of the Royal Astronomical Society*, astronomers revealed the young magnetar underwent an identity crisis. While being observed between June and July, J1818 flickered between emitting pulsarlike and magnetar-like radio pulses. But, over the course of 15 days, it eventually stabilized into a magnetar-like state.

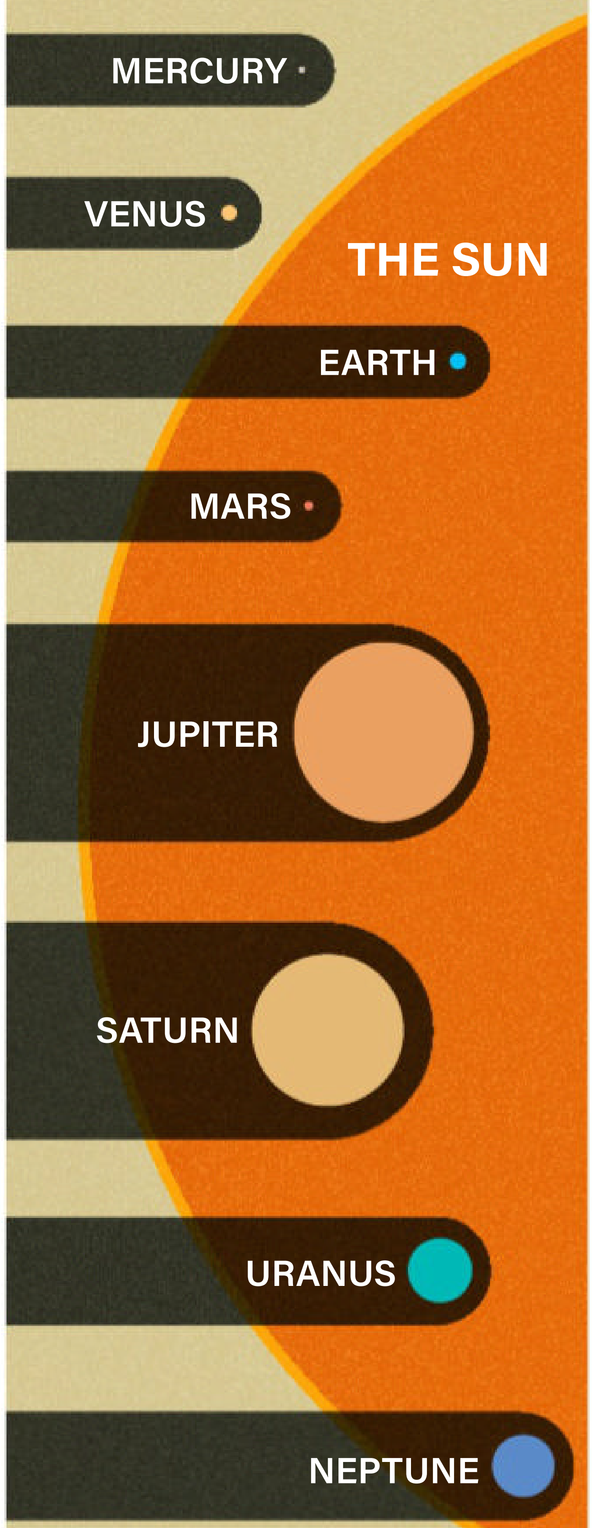
"This bizarre behavior has never been seen before in any other radio-loud magnetar," said study lead author, Marcus Lower of Swinburne University of Technology, in a press release. Further observations seem to indicate that J1818 has permanently settled into releasing magnetar-like pulses.

This study also discovered that J1818's magnetic poles appear misaligned, compared to suggestions from a theoretical model. Instead of aligning with its spin axis, the magnetar's magnetic poles appear to be just below its equator. J1818 is the first known magnetar to show such behavior.

"What's amazing about [magnetars] is they're quite diverse as a population," said Victoria Kaspi, director of the McGill Space Institute at McGill University in Montreal, Canada. "Each time you find one, it's telling you a different story. They're very strange and very rare, and I don't think we've seen the full range of possibilities."
—CAITLYN BUONGIORNO

# SOLAR SYSTEM SIZES

**THE SUN IS KING.** Among the planets, Jupiter and Saturn win the prize for size, dwarfing their fellow worlds. But the Sun is the true ruler of the solar system. Here's how the planets stack up in size (diameter), compared with our central star. — ALISON KLESMAN




**FAST FACT**

Although the Sun is only 10 times wider than Jupiter, you could fit more than 900 Jupiters inside the volume of our star.

*ASTRONOMY*: ROEN KELLY

# Pulsars hint at background sea of gravitational waves

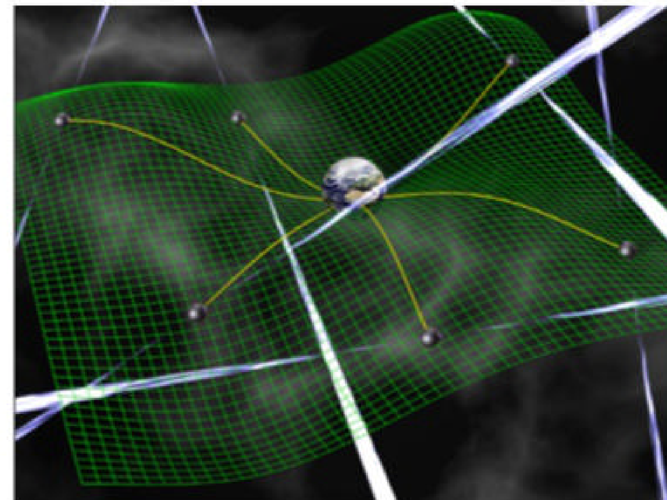
Astronomers have found the strongest evidence yet for a predicted class of gravitational waves created by supermassive black holes in the cores of galaxies.

Since the Laser Interferometer Gravitational-wave Observatory and Virgo collaborations announced the first detection of gravitational waves in 2015, scientists have identified a total of 50 gravitational wave events. These detections, which each send ripples through the fabric of the cosmos, have been traced back to the collisions of neutron stars or stellar-mass black holes.

But gravitational waves aren't only created by short-lived events such as collisions. Pairs of supermassive black holes lurking in the centers of some galaxies also etch long-wavelength gravitational waves into space-time as they slowly spiral toward each other. Each of these rumbles may take decades to wash over us, rather than the seconds-long "chirps" produced by shorter events. General relativity predicts Earth is constantly awash in gravitational waves like these, bobbing like a buoy at sea riding swells from distant sources of energy.

In a paper published December 2020 in *The Astrophysical Journal Letters*, a team reported the strongest evidence yet for this background sea of gravitational waves. The researchers are part of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), a project that uses data from the Green Bank Telescope and the now-defunct Arecibo Observatory. Since 2004, these massive radio telescopes have observed 47 pulsars — highly magnetic, spinning compact stars that emit beams of radio waves at incredibly consistent intervals as they rotate hundreds of times per second.

Together, this array of pulsars forms a galaxy-sized gravitational wave detector. If the space-time around Earth is stretched or compressed, the pulsar signals should arrive slightly early or late. In that case, any timing variations should be correlated in a pattern characteristic of gravitational waves, not simply random.



**SEA OF TIME.** A network of pulsars that spans the galaxy can help astronomers detect gravitational waves generated by binary supermassive black holes as they stretch and compress space-time, which should alter the timing of arriving radio signals. DAVID CHAMPION

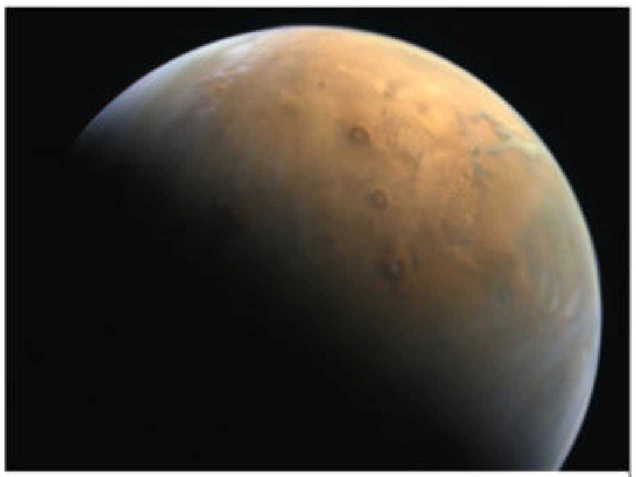
In their new paper, the team reports seeing such varying delays on the order of hundreds of nanoseconds, but they don't yet have enough data to claim to see the correlations that would mark a clear detection of gravitational waves. However, they have been able to eliminate alternative explanations for the variations, like uncertainty in the solar system's center of mass and interference from interstellar dust.

It's "a mic-drop moment," says Kelly Holley-Bockelmann, an astronomer at Vanderbilt University, who wasn't involved in the work. "I wouldn't bet my house that it's gravitational waves, but I would bet a very nice bottle of wine."

NANOGrav has two more years of data stored away that team members think will improve their signal enough to reveal a clear detection. Astronomers hope the gravitational wave background will clarify the physics of how supermassive black holes evolve. — M.Z.

**1,000** The estimated depth, in feet (305 m), of Titan's largest sea, Kraken Mare, a body of liquid methane that scientists hope to explore with a robotic submarine.

# Busy 2021 at Mars kicks off with Hope



**HOPE ARRIVES.** The first image of Mars returned by Hope after it entered martian orbit shows the three massive shield volcanoes of Tharsis Montes: Ascraeus Mons, Pavonis Mons, and Arsia Mons. To their right is the sprawling canyon system Valles Marineris; to their left, lying partly in shadow, is Olympus Mons, the largest volcano in the solar system. MBRSC/UAE SPACE AGENCY/CU-LASP/EMM-EXI

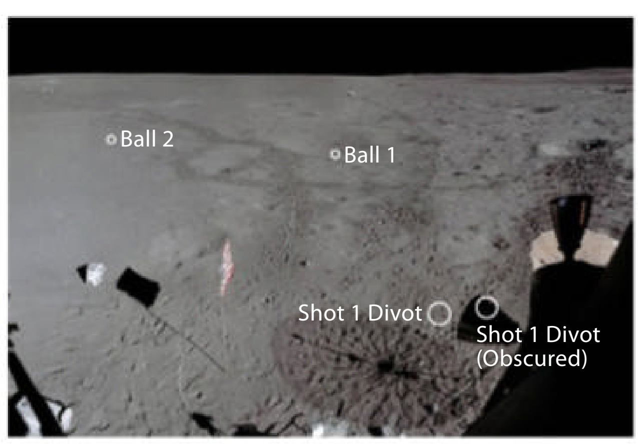
Last July, a trio of Mars-bound missions left Earth. On Feb. 9, the first craft reached its destination. The arrival of the United Arab Emirates' (UAE) orbiter — dubbed *al-Amal*, or Hope — coincides with the 50th anniversary of the country's independence, as well as marking the first interplanetary mission undertaken by an Arab nation.

"The launch of Mars Hope comes at the end of a six-year journey of development by the team," said Omran Sharaf, the Emirates Mars Mission lead, in a press release. "The mission has truly transformed The Emirates' capability in space systems engineering, science, and research, and had enormous positive impacts on our science community in general."

Hope will diligently observe the Red Planet's atmosphere, recording characteristics such as temperature, humidity, and dust levels for an entire martian year (687 Earth days). Researchers hope to track how molecules escape Mars' atmosphere into space — a process which, over billions of years, has transformed Mars from a wet, warm environment into a cold, dry, and dusty planet. The UAE has also announced it will freely share the Hope mission data with hundreds of institutions around the world, cementing its place as part of the larger science community.

With NASA's Perseverance rover safely on the surface, all eyes are now on China's Tianwen-1 mission, which entered martian orbit on Feb. 10, 2021, carrying China's first Mars rover. It is expected to attempt to land on the planet in May. –A.K.

# Moon golf shot measured




In the annals of golf history, Alan Shepard's shots from the lunar sand may be the most famous swings ever taken. Fifty years later, image analysis has finally determined how far his longest shot went. Image specialist Andy Saunders analyzed photos taken by the astronauts and video from the lunar ascent module as it lifted off from the surface. He managed to identify the golf balls, plus Shepard's footprints from his stance and his divot. By comparing the photos to more recent images from NASA's Lunar Reconnaissance Orbiter, he measured the distance of Shepard's second shot, which the astronaut had estimated at 200 yards (183 meters). The actual distance? A rather tame 40 yards (37 m). Still, that's not bad for a one-handed bunker shot in a bulky space suit. For the full story of Shepard's lunar golfing experience, see page 40. –M.Z.

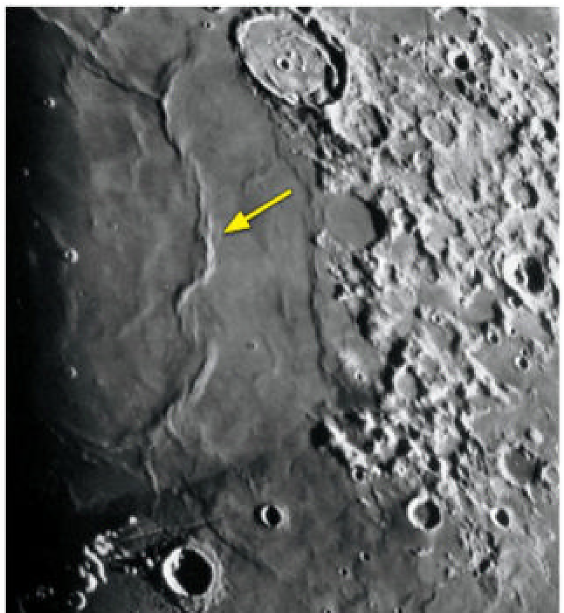
NASA, ESA, STSCI, AND J. BANOVETZ AND D. MILISAVLJEVIC (PURDUE UNIVERSITY)

## HUBBLE RECONSTRUCTS A SUPERNOVA

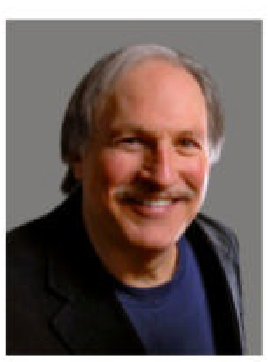
Thousands of years ago, light from a dying star in the Small Magellanic Cloud reached Earth. No records of the event exist, but it left behind a tangle of expanding gas and dust still visible today. Astronomers recently used the Hubble Space Telescope to reconstruct the blast and accurately determine its age: 1,700 years. Researchers rewound the clock by tracking 22 knots of material inside the supernova remnant, watching these clumps spread outward by comparing two images taken with the same camera 10 years apart. Based on the knots' motions, the team traced them to their point of origin — the site of the original supernova explosion — and determined how long the knots had been moving to reveal the age of the blast. –A.K.

# Duck sauce on eyepieces

Food fights are messy, but their metaphorical counterparts are part of the scientific process.



Formerly known as the Serpentine Ridge, the feature marked with the arrow on this lunar image is now known as *Dorsa Smirnov*, thanks to an IAU ruling. *CONSOLIDATED LUNAR ATLAS*/UA/LPL



**BY BOB BERMAN**
*Bob's newest book,* Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

Our story begins with food fights. Many readers will surely recall that beloved tradition, one largely incompatible with astronomy. The practice has been strangely overlooked by eyepiece companies, which fail to caution against it in their manuals on proper care of optics. As evidence that this magazine provides critical astronomy tips not found elsewhere, we'll get straight to the point: Avoid getting tartar sauce — or even ordinary barbecue sauce — on coated lenses.

But food fights can be metaphors for messy disagreements, too, and these are instructive because they gave us the state of astronomy today.

So, what are the top astrophysical food fights?

Most would immediately cite the 2006 International Astronomical Union (IAU) decision to demote Pluto from planethood. This ruling pitted astronomers against each other, often based on sentimentality, tradition, and nostalgia for a planet that shares a name with a certain cartoon dog. The consensus seems to be that Pluto was misclassified when it was first discovered — after all, many other similarly sized bodies that are not planets would have to become planets if Pluto were reinstated. And, anyway, no one has the stomach for going back into battle over it.

**Food fights can be metaphors for messy disagreements.**

But this controversy wasn't the first time the IAU got egg on its face.

Another big-time IAU food fight happened in the 1970s, when they decided to rename many of the Moon's features and give them Latin titles. For centuries, Moon-watchers using small telescopes took delight in seeing the low Sun highlight the many wrinkle ridges that cross the smooth, solidified lava seas. The largest, running north to south across the Sea of Serenity, was the Serpentine Ridge.

"We don't care if that's been its name for 200 years," said the IAU (in effect). "From now on, such ridges will be called *dorsa*." Lunar researchers quickly grabbed doughnuts for ammo. Even today, planetary scientist Charles Wood, in his preface to *21st Century Atlas of the Moon* (West Virginia University Press, 2013), insists the IAU "went crazy" and "introduced confusion and chaos," and refuses to label the beloved Serpentine Ridge with its new official designation of *Dorsa Smirnov*.

It got worse. Craters honoring famous people were also latinized. The crater Ptolemy is now *Ptolemaeus*. Chains of craters are now *catena*. Faults are *rupes*. Most of us have gotten used to it. But doughnut fragments still litter the landscape.

Sometimes the food fight is personal. Most astronomers admired Halton Arp's cranky stubbornness as he endlessly tried to show that high redshifts are not necessarily indicators of high recession speed and thus greater distance from Earth. His pet "proof" — Stephan's Quintet in Pegasus, where a seemingly attached-to-the-others galaxy has a disparate redshift — drew heated exchanges for years until the Hubble Space Telescope's ability to see individual stars in the outlier, NGC 7320, proved Arp was mistaken. NGC 7320 is not part of the group at all, but actually a foreground galaxy that lies much closer to Earth than the others.

Mistaken or not, determined astrophysicists doing the Don Quixote thing actually are part of science's precious process. Long after the martian canals controversy and the Great Debate over whether "spiral nebulae" like Andromeda were merely objects within the Milky Way, popular books sometimes offered wacky ideas that found support with a few astrophysicists, to the consternation of the majority. In 1950, Immanuel Velikovsky's *Worlds in Collision* claimed Venus is a newborn planet, ejected by Jupiter as a clump of material that initially roamed the solar system as a comet. He also claimed biblical events could be explained by this pre-Venus comet. According to him, the "manna from heaven" that purportedly fed the fleeing Israelites was actually bits of edible comet fragments falling from the sky. It made sense since comets, he insisted, contain carbohydrates.

For years, the idea had adherents. Finally, astronomers had had enough. Not only did Velikovsky's theory dismiss well-understood celestial mechanics, they said, but in suggesting people could munch on comet material, Velikovsky was obviously mixing up carbohydrates with hydrocarbons. Actually, Venus' atmosphere had been found to contain neither. Still, the nutriment legacy lingers when we say that comets come here from the "ort cloud."

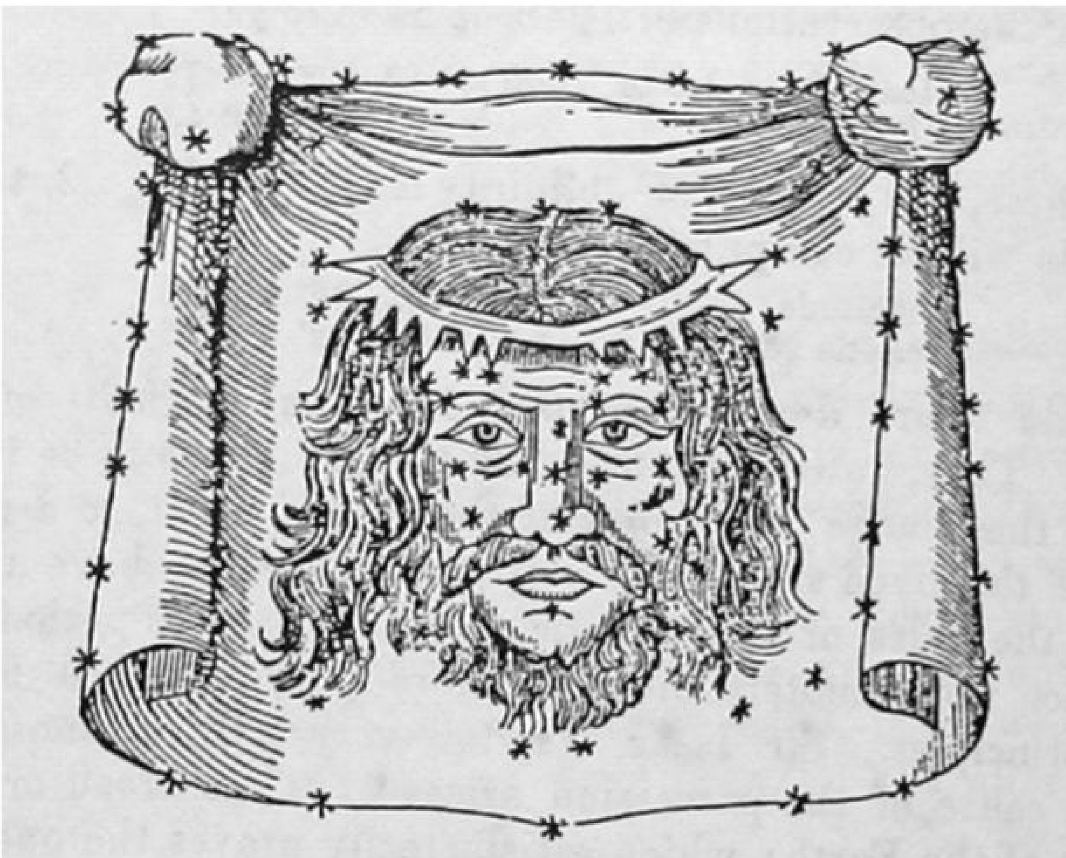
These days, the food fights continue. We have one camp arguing for dark matter and the other thinking that gravity behaving oddly at low levels can better explain the observations of galaxies' rotation. And we have one camp believing we can do more solar system science with automated probes, while another pushes for crewed visits to other planets.

It never ends. And hopefully, it never will.

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

# Unveiling Veronica's Veil

For centuries, a lost asterism has been hiding in plain sight.



When George F. Chambers revised William Henry Smyth's *A Cycle of Celestial Objects* in 1881, he called this figure "a pious fraud." STEPHEN JAMES O'MEARA

**BY STEPHEN JAMES O'MEARA**
*Stephen is a globe-trotting observer who is always looking for the next great celestial event.*

In 1643, Antonius Maria Schyrleus de Rheita, an astronomer and friar of the Catholic Church's Capuchin Order, detected through his binocular telescope a stellar grouping resembling the sacred *Sudarium Veronicae*, or the Veil of St. Veronica. According to the Christian Stations of the Cross, when Veronica used this cloth to wipe the face of Jesus on his way to Calvary, it took on the impression of his face. But the knowledge of which stars formed this asterism has been lost to time. Since de Rheita's original observation, there have been no other recorded sightings — until, perhaps, now.

## A problematic portrait

Before we share the solution, let's look first at the problem. To search for the Veil, many observers (myself included) relied on an illustration by Joannes Zahn, first published in 1685. It was then reproduced in Admiral William Henry Smyth's classic 1844 book, *A Cycle of Celestial Objects.*

Smyth writes that de Rheita saw the figure "most clearly, by means of his binocular telescope." This description suggests binoculars or a small telescope are required to see the star pattern. But where do we look?

Smyth tells us Veronica's Veil is between the celestial equator and the zodiac, on or near the spot of NGC 3166. This description places the asterism roughly 10° south of Regulus, in the constellation Sextans. No apparent size or orientation is offered, leaving much room for speculation. The search, then, has long been for a binocular or telescopic asterism in Sextans.

But we were horribly wrong. It turns out that Zahn's figure does not fit de Rheita's description and is most likely — as George F. Chambers's caption reads for Zahn's illustration in his 1881 revision of Smyth's work — "a pious fraud."

**The Veil is a naked-eye asterism with a splash of telescopic stars within.**

## A stellar unveiling

In a 2017 article in the *Journal for the History of Astronomy*, artificial intelligence researcher, Latin scholar, and astronomy author Michael A. Covington of the University of Georgia proposed an outstanding solution to the long-standing mystery.

The key was his translation and interpretation of the discovery letter de Rheita wrote to his friend, Juan Caramuel, on April 24, 1643. In it, we learn of critical facts not presented by Smyth — namely, that the asterism is visible to the naked eye as well as through a Galilean telescope. Furthermore, de Rheita tells us that the four corner stars of the Veil are bright.

In other words, the Veil is a naked-eye asterism with a splash of telescopic stars within. And when Covington searched for four naked-eye corner stars that "look like an unfolded veil or handkerchief," he found "a rectangular


pattern of stars in that area, covering nearly the whole space between the equator and the ecliptic." The stars were Rho (ρ) and Omicron (ο) Leonis to the north, and Beta (β) Sextantis and Iota (ι) Hydrae to the south.

He also found a smaller rectangle whose corners are marked by 31 and Omicron Leonis to the north, and Alpha (α) Sextantis and Iota Hydrae to the south. Both rectangles fit de Rheita's description. "Whether the interior stars resemble a face is not obvious," Covington says, "but there are definitely several naked-eye stars present, and the main rectangle contains approximately 200 stars down to magnitude 9, which is a reasonable limit for a 17th-century telescope."

## Seeing is believing

After reading Covington's article and going out to hunt down his proposed Veil, I did a double take. It was remarkably obvious, even under bright moonlight. I mentally congratulated him for finally discovering a near-indisputable candidate for this lingering celestial mystery.

I found the larger version of Covington's Veil candidate to be the more compelling solution for the cloth (as drawn by Zahn), though I could only imagine a face in the smaller rectangular section to the west. That view also matches what de Rheita told Caramuel: that the "very bright small stars [are] densely crowded in the middle, like a swarm of bees."

Once seen, the large version of the Veil was hard to erase from view. Perhaps, as de Rheita wrote to Caramuel, "so quickly impressed this likeness intuitively on the mind and eyes, that looking at it a hundred times over and over, it would not be possible to attach to it any image more similar to it than the Veil of Veronica." Go out and try to track down Covington's fascinating discovery and let me know your thoughts at sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT
**www.Astronomy.com/OMeara**

ABOVE: Here are various views of the candidate starfield discovered by Michael A. Covington that represents the *Sudarium Veronicae*, imagined by Antonius Maria Schyrleus de Rheita, including, in the middle frame, the depiction created by Joannes Zahn. Note that in 1643, Iota Hydrae, Alpha Sextantis, and Beta Sextantis were all north of the celestial equator. STEPHEN JAMES O'MEARA

LEFT: The *Face of Christ on St. Veronica's Veil* is rendered in this 1735 French engraving. HARRIS BRISBANE DICK FUND, 1917/ METROPOLITAN MUSEUM OF ART

# Breakthrough

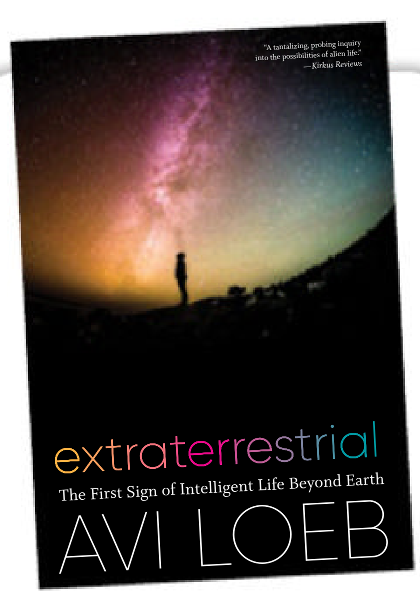
# *A voyage to the stars*

Using laser-propelled lightsails, tiny spacecraft could venture to the Sun's nearest neighbor in just a few decades. **BY JAKE PARKS**

On Nov. 6, 2018, as millions of Americans cast their votes in a hotly contested midterm election, astrophysicist Avi Loeb sat in his office surrounded by four television crews. Loeb, chair of Harvard University's Department of Astronomy and author of the new book *Extraterrestrial* (Houghton Mifflin Harcourt, 2021), was not being targeted for his political insight. Instead, the media attention was due to his recent eye-catching paper exploring whether the interstellar space rock ʻOumuamua was really a piece of alien technology that's sailing on sunlight.

Loeb first pondered the possibility that the solar system's first known interstellar interloper was an extraterrestrial craft back in late 2017, shortly after astronomers discovered the object (formally known as 1I/2017 U1) using the Pan-STARRS telescope at Haleakalā Observatory in Hawaii. But it wasn't until he began exploring what he himself describes in his book as "an exotic hypothesis, without question" that he began to take it seriously — if only as a thought experiment.

He drew his ʻOumuamua hypothesis from what was fresh in his mind. At that point, Loeb had spent the previous few years working with some of the world's brightest and most ambitious people to develop an audacious interstellar mission that would use lightsails to venture to a nearby star. The moonshot project, fittingly called Breakthrough Starshot, aims to create a tiny spacecraft equipped with a sail that will catch a brief burst of powerful laser light, propelling it to some 20 percent the speed of light. At that rate, such a craft would arrive at the nearby star Proxima Centauri within about 20 years of launch.

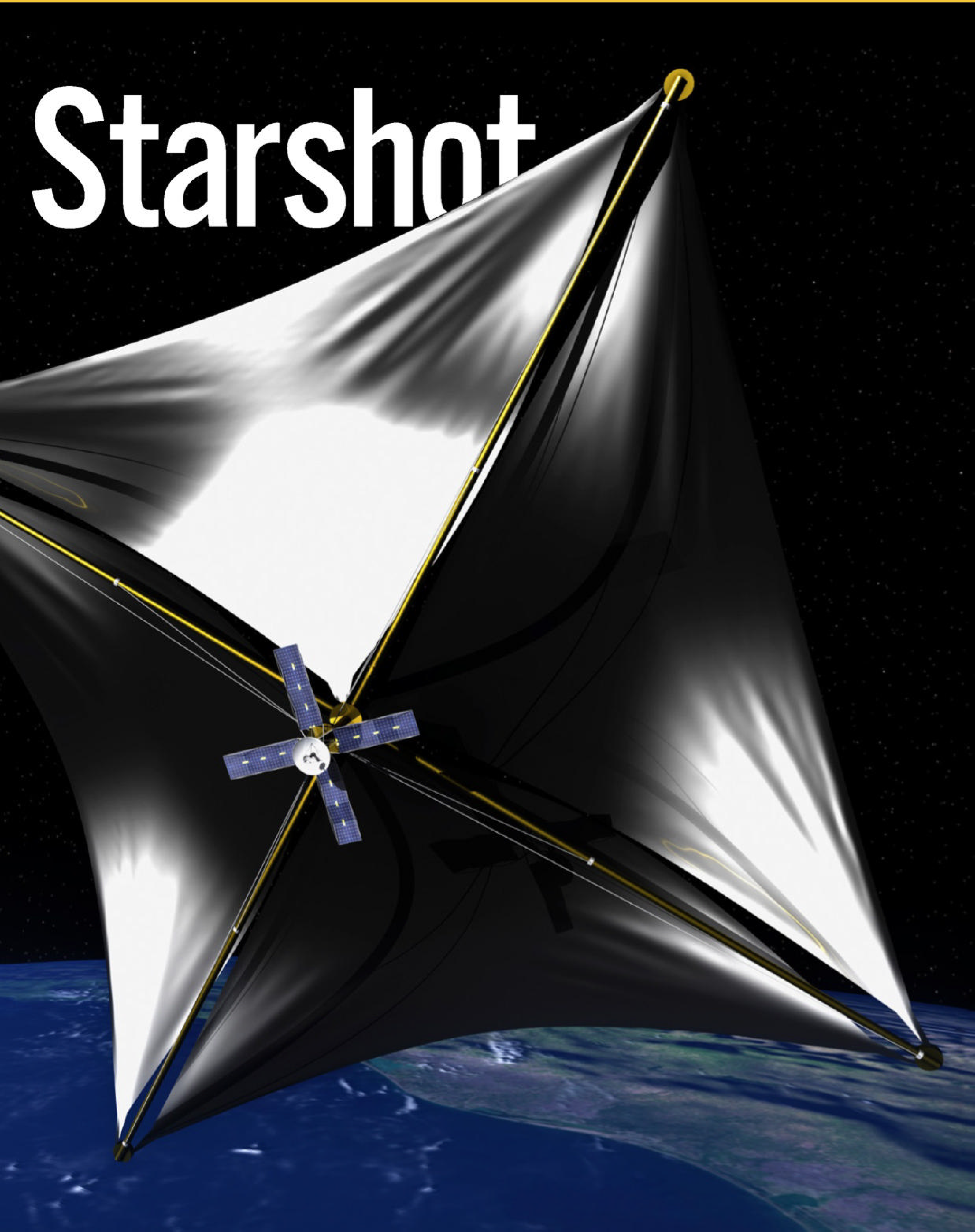



COURTESY OF HOUGHTON MIFFLIN HARCOURT/AVI LOEB

Pick up your copy of *Extraterrestrial* at **www.MyScienceShop.com/product/book/81564**

A tiny nanocraft attached to a large lightsail might be humanity's best bet for reaching another star within a generation. BREAKTHROUGH INITIATIVES

# Starshot

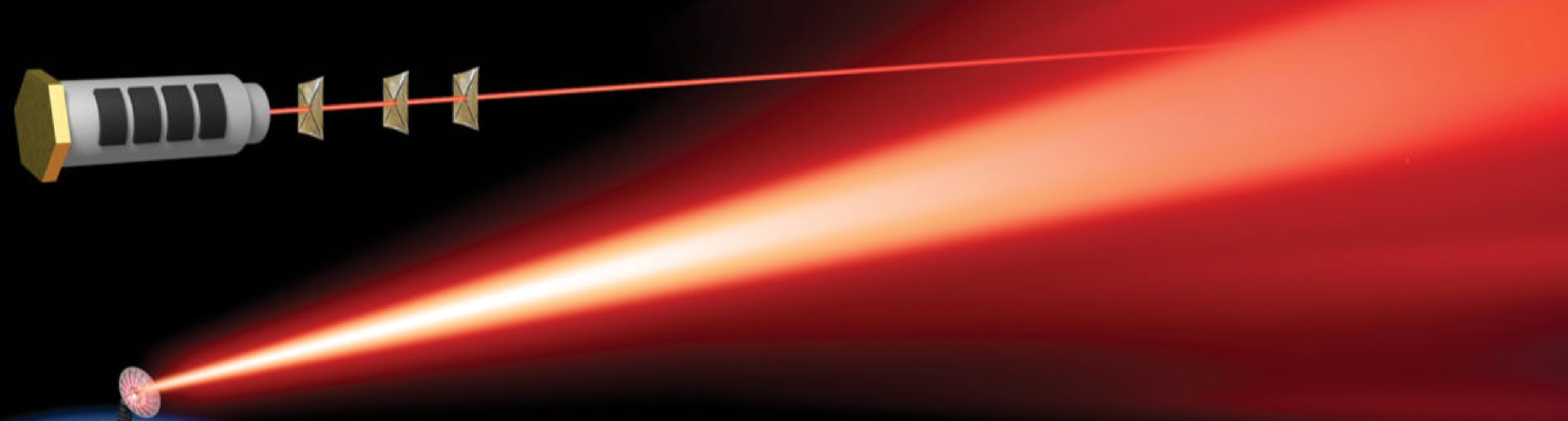


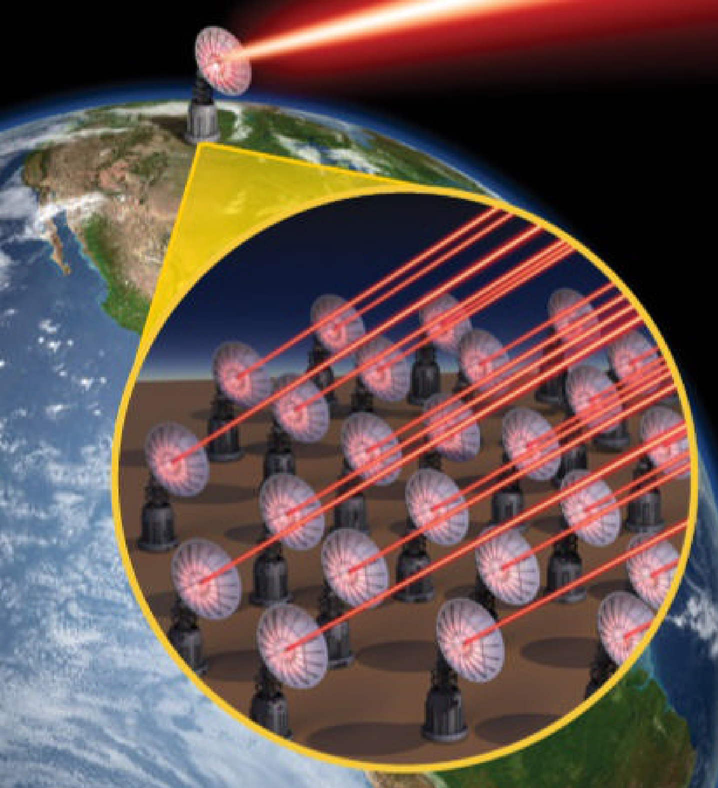
# How to speed to a nearby star

## *Sailing on light*

One fundamental property of electromagnetic radiation, or light, is that it has momentum. This means that despite having no mass, particles of light can transfer their momentum to macroscopic objects. And one way to harness that momentum is to mimic how sailboats harness the momentum of rushing air molecules.

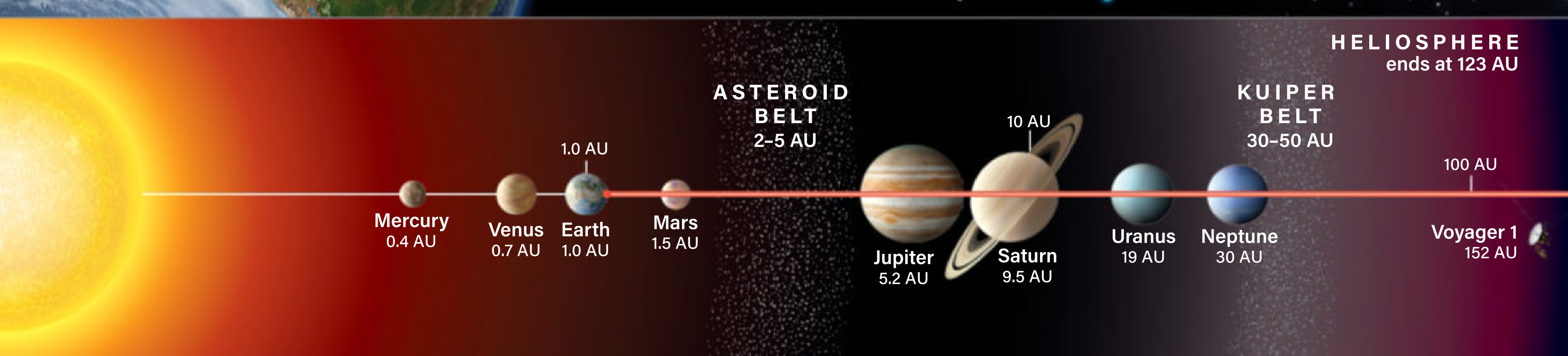
Enter the lightsail: an ultra-thin, incredibly reflective sheet of material. As light hits a lightsail, it bounces backward, imparting its forward momentum to the sail itself. This can propel a spacecraft through space. But unlike water slowing ships in the ocean, there isn't much material in space that a sailing craft must push through. So, a cosmic vessel will continue accelerating as long as it's being pushed by light. That means lightsail-equipped spacecraft (deployed by a mothership and targeted by lasers) could theoretically reach a significant fraction of the speed of light in just a few minutes.





## *Propelled by lasers*

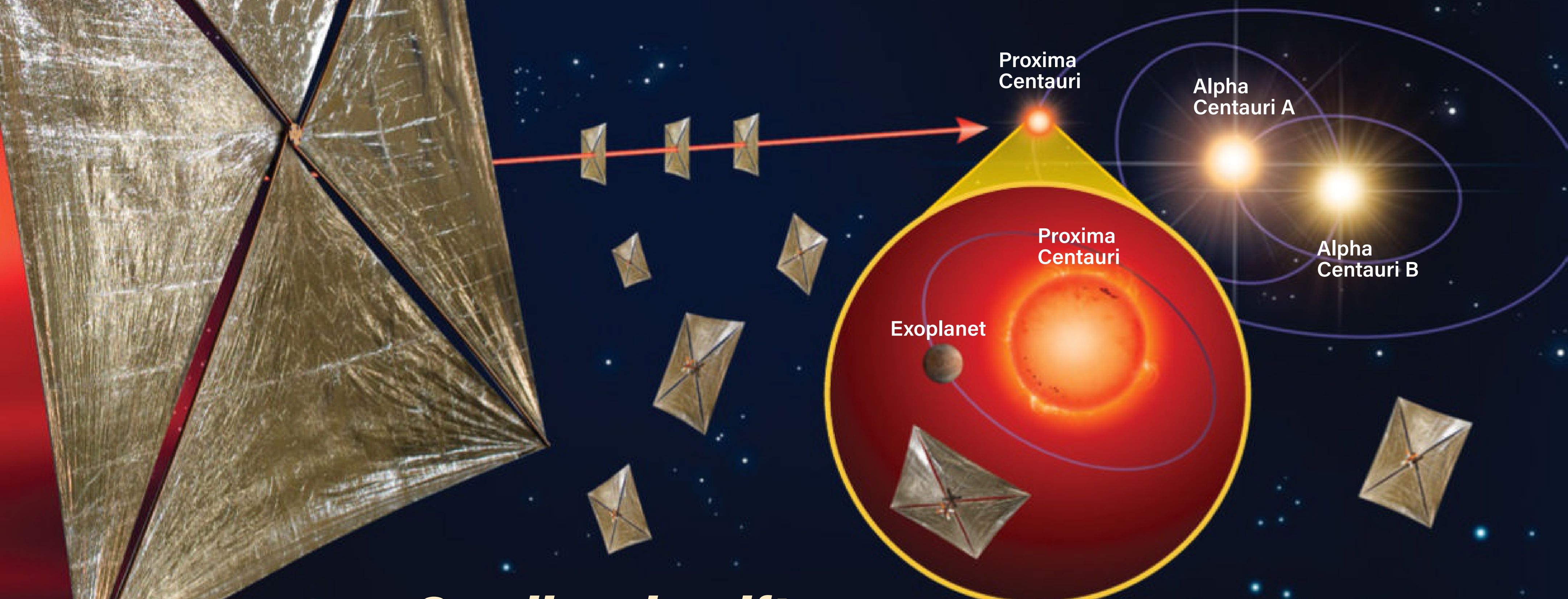
Interstellar cruises powered by light will not only require sails, but also many lasers that are perfectly phased together. Furthermore, those lasers would draw an incredible amount of power — even if just for a few minutes a day. According to Loeb, propelling a lightsail-equipped nanocraft, or StarChip, would require hundreds of individual lasers spanning roughly 250 acres (1 square kilometer). The array would also need access to enough energy to fire a coherent 100-gigawatt laser beam for several minutes during each and every launch. That's about 100 times more power than the *Back to the Future* movies' DeLorean used to go back in time, or roughly the amount of power generated by all the nuclear power plants in the U.S. in a given year.



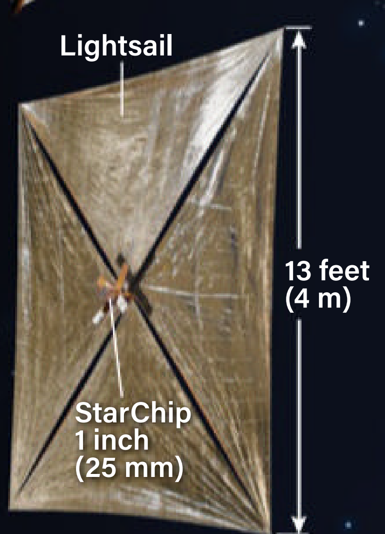
## *Taking a closer look*

When a StarChip (or a fleet of them) finally reaches Proxima Centauri, its navigation system will likely orient the craft using four built-in photon thrusters, each capable of firing a roughly 1-watt diode laser. This would allow the StarChip's various onboard devices — such as cameras or magnetometers — to gather scientific data on specific targets as they unstoppably zip by.

Whether from observing Proxima Centauri, its exoplanets, or intriguing asteroids and comets that are circling the red dwarf, the data would then be beamed back to Earth via a transmitter. (The Breakthrough Starshot team is also considering using the lightsail itself as a primary reflector for the transmitter.) Four years later, scientists would finally receive and analyze the StarChips' data — that is, assuming they have built the roughly 30-meter-diameter receiving telescope needed to pick up the signal on Earth.




## *Small and swift*

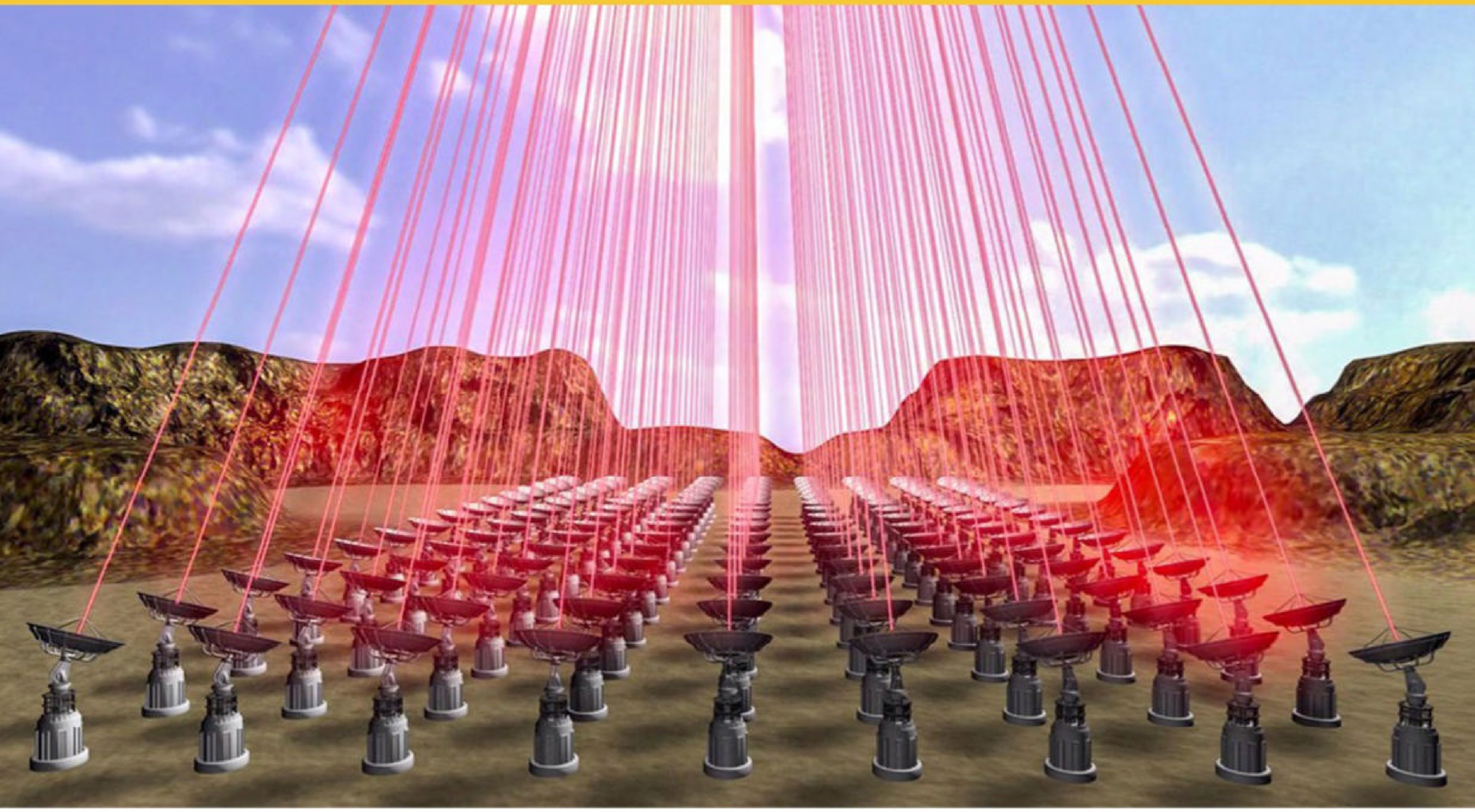



A necessary requirement for the Breakthrough Starshot mission is keeping the mass of each sail-equipped StarChip to just a few tenths of an ounce. But thanks to dramatic decreases in the size of microelectronics over the years, the mission team is confident their gram-scale craft will be able to include an onboard power supply (likely an atomic battery powered by radioactive decay), navigation and communication equipment, and even tiny thrusters to adjust its orientation as it approaches its target.

Likewise, the solar sail itself, which is expected to span up to around 13 feet (4 meters), will need to weigh in at less than about 0.035 ounce (1 gram). It will also need to be extremely thin, as otherwise the sail would absorb far too much heat and be vaporized by the barrage of laser light. Fortunately, rapid advances in microfabrication are leading to increasingly lightweight and ultrathin materials that could potentially fit the bill, including graphene. —*J.P.*

*ASTRONOMY*: ROEN KELLY


*Logarithmic scale; planet and star sizes are not to scale*
*Astronomical unit (AU) = 92,955,807 miles (149,597,871 km)*



An array of lasers, seen in an artist's concept, would create a roughly 100-gigawatt beam to propel each StarChip to 20 percent the speed of light in just minutes. BREAKTHROUGH INITIATIVES

## Visiting Proxima Centauri

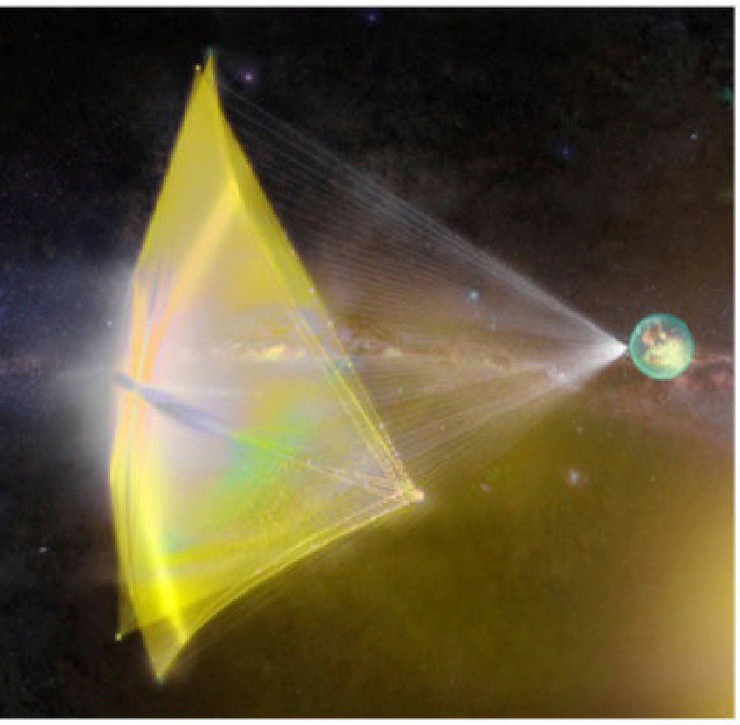
Exploring the world and universe around us is one of humanity's most instinctual traits. And although this exploration is often difficult and dangerous, the potential rewards tend to justify the risks. Humans are willing to sacrifice a lot to learn what lies beyond the horizon. And now, for the first time in history, humanity seems to be on the precipice of literally reaching out and touching the stars.

It's not going to be easy, though. The closest star to Earth after the Sun is Proxima Centauri — a red dwarf with just over one-tenth the mass of our star located some 4.24 light-years away in the Alpha Centauri system. Given our Milky Way is some 100,000 light-years across, 4.2 light-years might seem like a stone's throw. But it's not. At that distance, which is equivalent to about 25 trillion miles (40 trillion kilometers), it would take our swiftest modern spacecraft about 100,000 years to reach our nearest neighbor. After all, it takes light — the Usain Bolt of the universe — more than four years to run the same race.

The reason? Mass. Mass is the bane of accelerating objects to great speeds. To significantly increase the velocity of a heavy object takes a tremendous amount of energy. So, if the goal is to reach a distant star in a reasonable amount of time, say, within a generation, a spacecraft must be extremely tiny and, therefore, robotic. Plus, it still requires an insanely energetic boost to get up to speed.

That's the basic premise of Breakthrough Starshot: Design a lightsail-equipped nanocraft (named StarChip), give it a powerful push, and let it zip off to Proxima Centauri at more than 130 million mph (216 million km/h). Oh, and while we're at it, we might as well send a fleet of hundreds or thousands of StarChips to ensure at least some succeed.

Simple, right? In theory, yes. In reality, it's going to take a huge amount of work, many technological breakthroughs, and, of course, a ton of money. But what better time than the present to start such a humanity-defining mission?



Each lightsail would be limited to about one-thirtieth of an ounce (less than 1 gram) while still being incredibly reflective. KEVIN GILL

## Setting sail in space

To quickly travel to another star, it's clear a spacecraft must be small. But it also needs a strong push to get started. One possible way to do that is borrow a tool pirates used to help them plunder the seven seas: sails. However, instead of catching wind, StarChip's sails would catch powerful beams of laser light.

Loeb, chair of Breakthrough Starshot's advisor board, is quick to note that the first mention of cruising through the cosmos on celestial winds dates back to a 1610 letter from astronomer

Johannes Kepler to his friend Galileo Galilei. In it, Kepler writes, "With ships or sails built for heavenly winds, some will venture into that great vastness." However, the true potential of using sunlight to sail through space wasn't fully recognized until the work of Soviet rocket pioneers Friedrich Sander and Konstantin Tsiolkovsky in 1924. Then, in the 1960s, Hungarian astrophysicist György Marx pushed the idea further by pondering whether a directed beam of energy, rather than sunlight, could be used to propel such a spacecraft.

American physicist and science-fiction writer Robert Forward took the lead in the 1970s, further developing the lightsail concept. By 1984, Forward's work led him to publish a paper in the *Journal of Spacecraft and Rockets* titled "Roundtrip Interstellar Travel Using Laser-Pushed Lightsails." In it, he outlined how the laws of physics did not forbid using lightsails to venture to other stars. However, Forward also noted that "whether it can be engineered and is financially or politically feasible is left for future generations to determine."

Despite the daunting, multipronged challenge of interstellar travel, in 1985, Forward created actual plans for an ultra-light interstellar probe powered by microwave lasers, or masers. He called it Starwisp and, in the 1990s, NASA Glenn Research Center scientist Geoffrey Landis jumped into the fray to elaborate on Forward's basic design. But Starwisp never took flight. In 2005, the Planetary Society launched its own solar sail, Cosmos-1, but it failed to reach orbit.

Finally, in 2010, nearly a century after the notion of sailing on sunlight was first outlined in detail, the Japan Aerospace Exploration Agency (JAXA) successfully launched a solar sail named Interplanetary Kite-craft Accelerated by Radiation of the Sun (IKAROS), which hitched a ride to Venus with the climate orbiter Akatsuki. Once in position, IKAROS cleverly spun at some 25 revolutions per minute to unfurl its 46-foot-wide (14 m) sail, which was just 0.0003 inch (7.5 micrometers) thick — or about one-third the width of a human hair. Within a month, JAXA reported photons from the Sun were indeed accelerating IKAROS as planned, boosting its speed by a relatively modest 890 mph (1,430 km/h). And by utilizing adjustable LCD panels embedded near the edges of its sail, the spacecraft was even able to adjust the force pushing against it, changing its orientation at will.

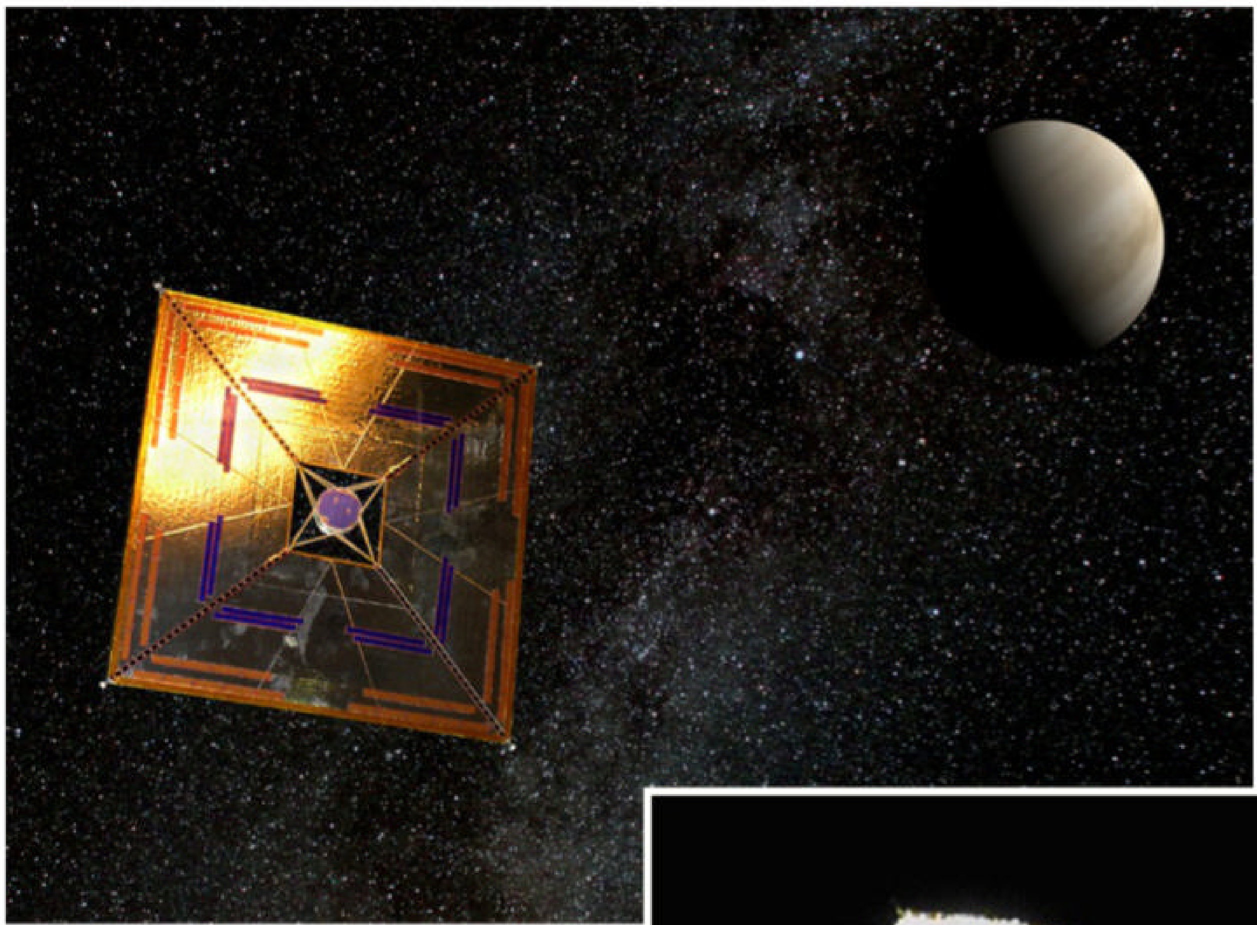
With the technology behind lightsails finally proven to work in space, Russian billionaire Yuri Milner picked up the ball a few years later. In May 2015, Loeb says, Milner nonchalantly asked him to look into the idea of interstellar spacecraft that could sail on light. The task took the eternally inquisitive Loeb and his team some six months to exhaustively research.

By early 2016, Milner was convinced an interstellar mission was feasible — or at least soon would be if technology continued to sprint forward. He officially kicked off the Breakthrough Starshot project by contributing $100 million of his own money to fund proof-of-concept research and development not just for lightsails, but also for the other advanced technology required to send a craft to another star within a generation. Ever since, dedicated scientists and engineers have been tirelessly working to make this ambitious dream a reality, taking advantage of additional funding from multiple NASA grants.

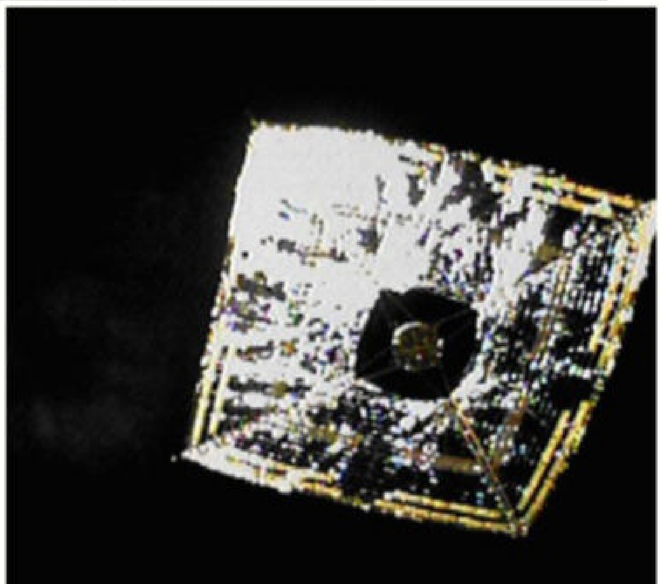
> "With ships or sails built for heavenly winds, some will venture into that great vastness." *—Johannes Kepler, 1610*

## Starshot progress so far

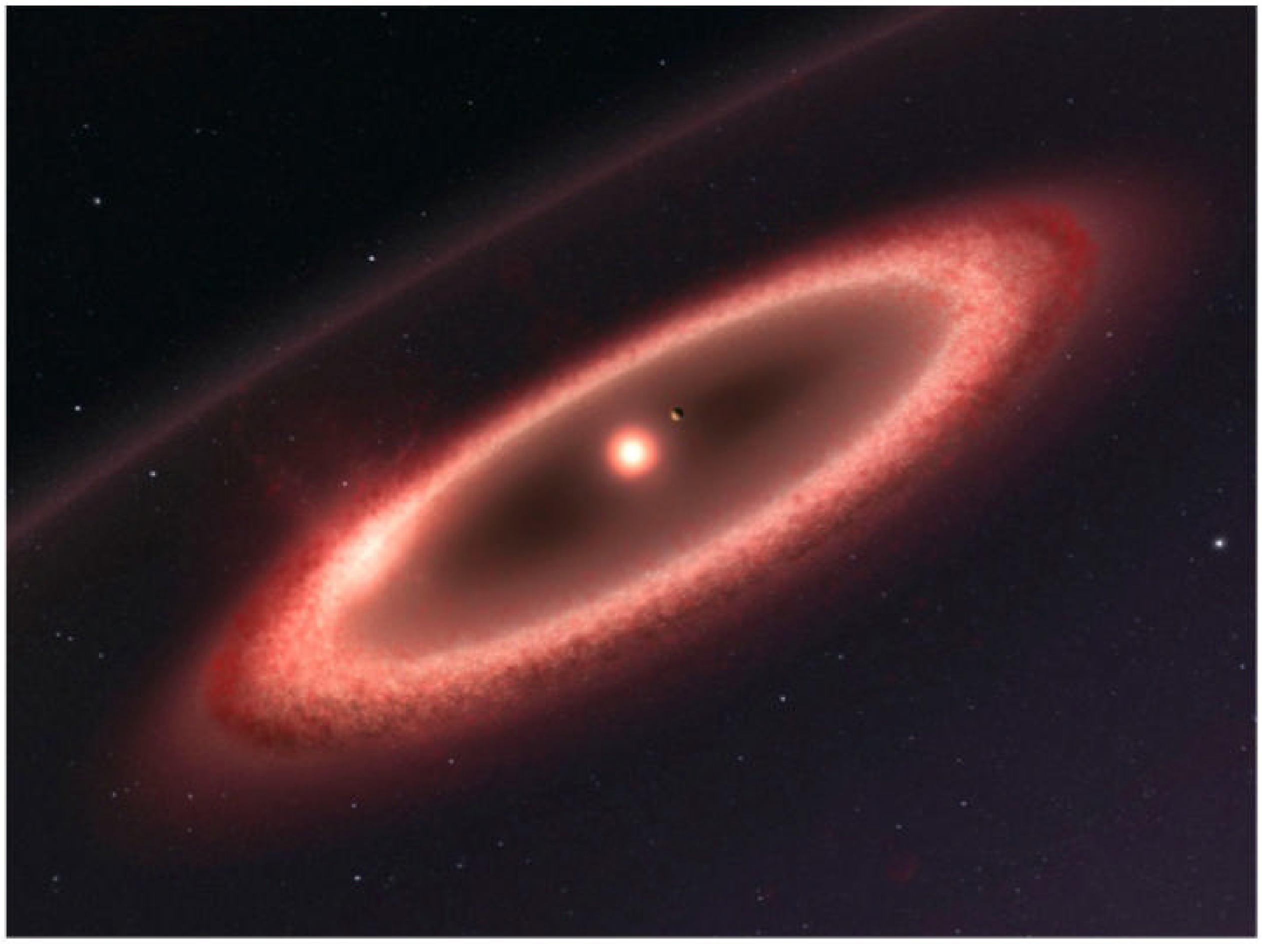
It's important to remember that Breakthrough Starshot is still in its early infancy. The initiative has made some impressive strides, but there's still a long way to go. For instance, if Breakthrough Starshot is really going to accelerate a spacecraft to 20 percent the speed of light, that craft will need to be roughly 1/1,000 the mass of IKAROS, which weighed in at about 4.4 pounds (2.2 kilograms). That means Starshot will



IKAROS, seen in this artist's concept, proved solar sails work in space by harnessing sunlight to boost its speed by 890 mph (1,430 km/h). ANDRZEJ MIRECKI/WIKIMEDIA COMMONS



This real image of IKAROS was taken after it deployed its sails on June 14, 2010. The proof-of-concept mission tagged along to Venus with JAXA's climate orbiter Akatsuki. JAXA

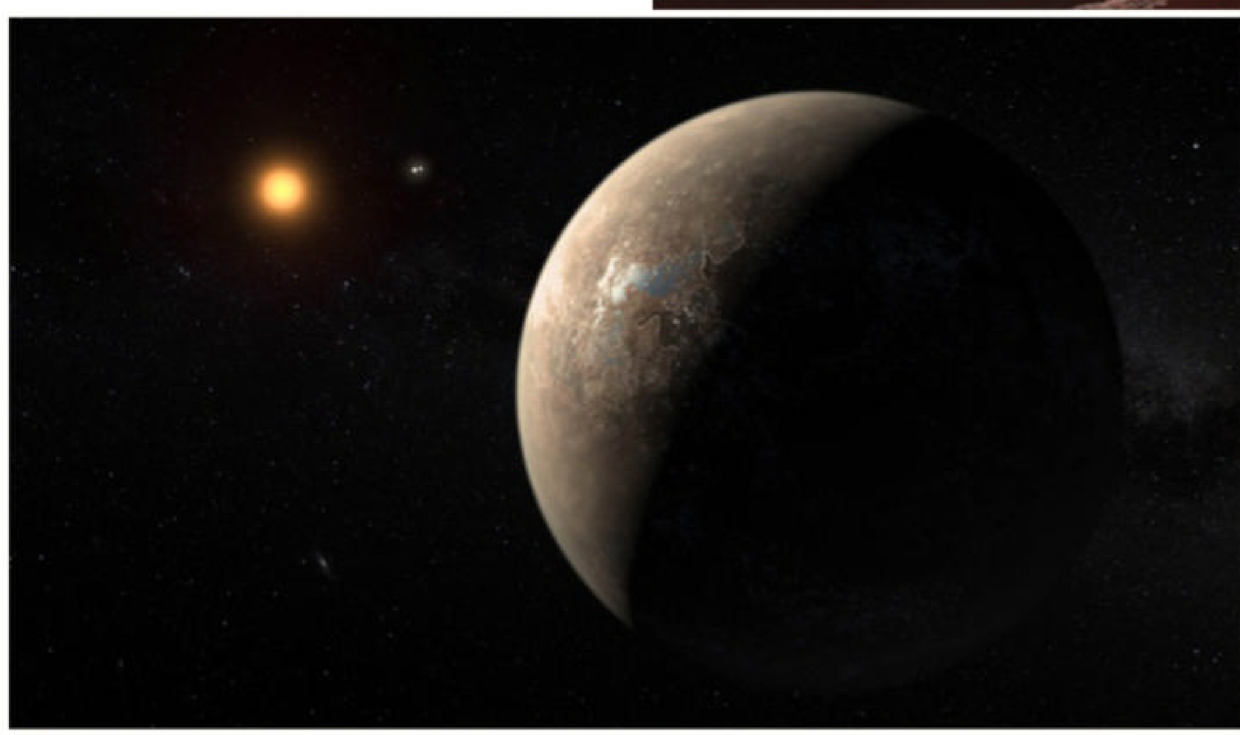


Using the Atacama Large Millimeter/submillimeter Array, astronomers detected evidence of a dust belt around the nearby red dwarf Proxima Centauri, seen here in an artist's concept. ESO/M. KORNMESSER

have to pack everything it needs for a four-year interstellar trip into a suitcase no heavier than a few paperclips.

Fortunately, thanks to Moore's law — which predicts a biennial doubling in the number of transistors that can fit on a microchip, enabling smaller, more powerful devices — that challenge is quickly becoming less of an issue. Tiny electronics already exist that are capable of some pretty amazing things. For instance, engineers have developed affordable cameras that weigh around a gram and are able to capture resolutions of at least 200 by 200 pixels. That's not much by today's smartphone standards, but it's still sharp enough that one mounted to a StarChip could resolve exoplanetary continents and oceans as it zips by. And the Breakthrough Starshot team has their bar set even higher: They are counting on technological improvements in upcoming years that will allow for ultralight cameras capable of snapping roughly 20-megapixel pics.

The sail itself also needs to be extremely light. Fortunately, the cost of manufacturing high-quality, nanoscale materials is constantly dropping. Unfortunately, weight isn't the only issue when it comes to lightsails. According to Loeb, to avoid being vaporized by



The star Proxima Centauri is orbited by at least two exoplanets: Proxima Centauri b (seen in the foreground of this artist's concept) and Proxima Centauri c (not pictured). The red dwarf star is also part of the Alpha Centauri triple-star system. ESO/M. KORNMESSER

100 gigawatts of laser light, a sail must only absorb (rather than reflect) about 1 out of every 100,000 photons that strike it. From a material standpoint, that's a major challenge. Loeb says the team is looking into building such a sail out of graphene, but so far, they haven't yet been able to create an ideal prototype.

However, the Starshot team has successfully launched other prototype craft in recent years, testing various aspects of their design and technology. For instance, in 2017, researchers sent six tiny craft, each weighing about 0.14 ounce (4 grams), into low Earth orbit. Dubbed Sprites, these chips included solar panels, computers, sensors, and communication equipment on a square frame just 1.4 inches (3.5 cm) wide. And though the researchers never established communication with most of the Sprites, they did get a signal from at least one, proving such miniaturized communication and power systems can function in space.

Then in 2019, the initiative sent another tiny prototype some 100,000 feet


**In the likely best-case scenario, Breakthrough Starshot might begin launching StarChips to Proxima Centauri by the mid-2030s.**

(30,500 m) above Earth to snap pictures of our planet's surface. The test captured some 4,000 shots during its flight, spawning much discussion about what equivalent images of the two known exoplanets around Proxima Centauri might look like.

## A long way to go

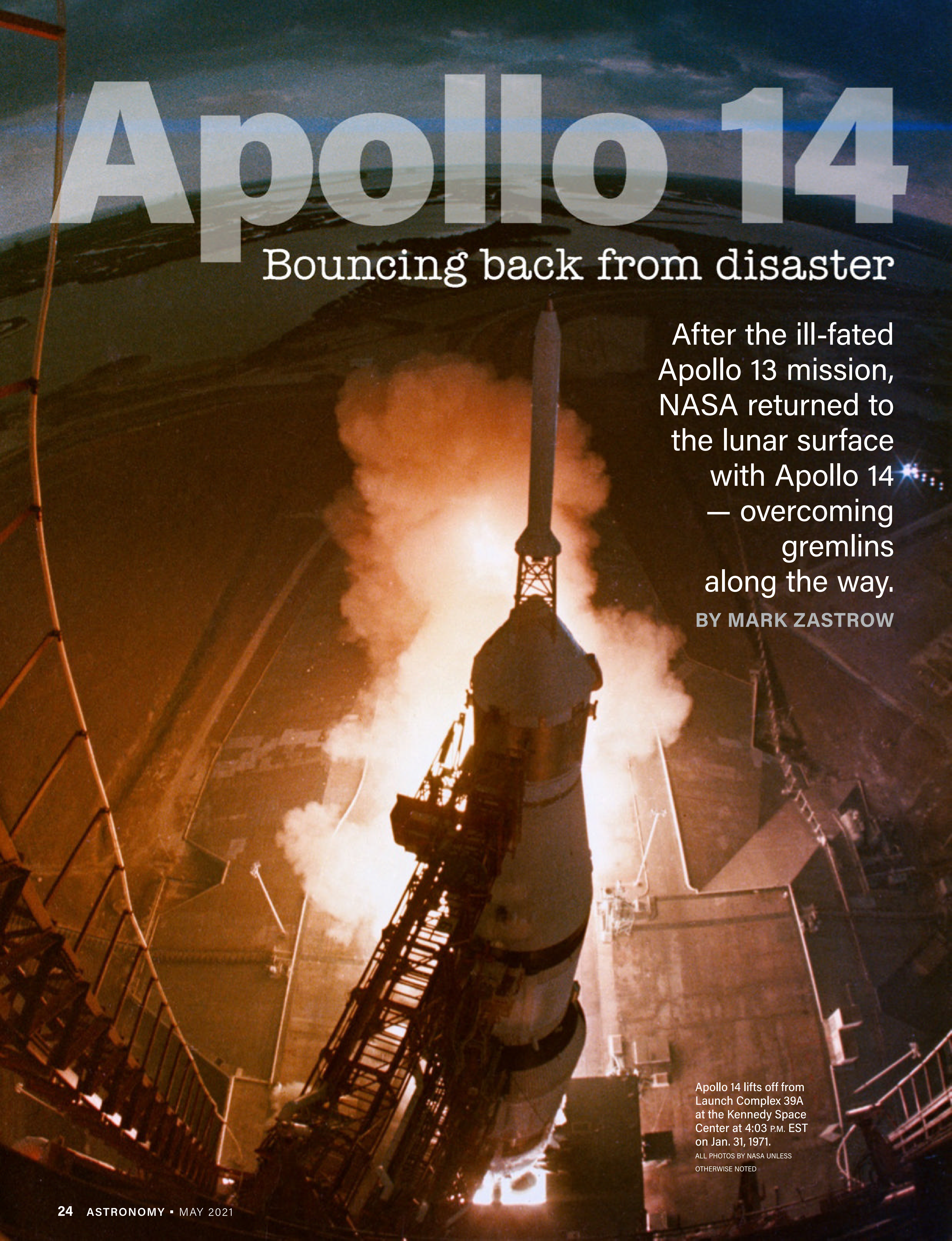
With more than $100 million in funding so far, Breakthrough Starshot is already off to a strong start, but it will inevitably cost billions to become a reality. However, according to Loeb, that puts it right in line with some of the world's other most ambitious (and expensive) science projects, such as the Large Hadron Collider and the upcoming James Webb Space Telescope, which cost about $5 billion and $10 billion, respectively. Fortunately, as technology matures, the team expects the cost of each launch to fall to a few hundred thousand dollars. That's still a lot of money, but obtaining up-close views of our nearest exoplanetary neighbors borders on invaluable.

In the likely best-case scenario, Breakthrough Starshot might begin launching StarChips to Proxima Centauri by the mid-2030s. Factoring in 20 years of travel time and four more years of waiting for the data to make it back to Earth, researchers wouldn't get the first up-close and personal views of a star and planets beyond our solar system until at least 2060. And Milner said in a 2016 interview that it will likely take closer to a generation (perhaps 25 to 35 years) before the first trip is underway.

Supporting and funding a project that, optimistically, doesn't launch until 2060 might seem like a frivolous venture to some — especially considering the slew of pressing events that have unfolded on Earth so far this decade. But as award-winning *Cosmos* writer and producer Ann Druyan, a member of the Breakthrough Starshot advisory board, said during a 2016 press conference announcing the initiative: "Science thinks in timescales of billions of years. And yet, we live in a society that only thinks in terms of, generally, the balance sheet of the next quarter or the next election. … So, this kind of thinking that looks at a horizon that's 35 years away — possibly 20, possibly 50 — is exactly what's called for now, because it's this kind of multigenerational enterprise that nets us such great results."

Loeb shares that same sentiment but puts it more succinctly by quoting Oscar Wilde: "We are all in the gutter, but some of us are looking at the stars."

**Jake Parks,** *associate editor at* Astronomy, *calculated it would take him approximately 190 billion years to reach Proxima Centauri when traveling at his fastest sprint speed.*



# Apollo 14

## Bouncing back from disaster

After the ill-fated Apollo 13 mission, NASA returned to the lunar surface with Apollo 14 — overcoming gremlins along the way.

**BY MARK ZASTROW**

Apollo 14 lifts off from Launch Complex 39A at the Kennedy Space Center at 4:03 P.M. EST on Jan. 31, 1971.

ALL PHOTOS BY NASA UNLESS OTHERWISE NOTED

## IF AT FIRST YOU DON'T SUCCEED, FLY, FLY AGAIN.

That could have been the mantra for Apollo 14 — a mission that marked a triumphant comeback for NASA after the near-catastrophe of Apollo 13.

Apollo 14 was originally slated to land at Littrow Crater in October 1970. But after Apollo 13 was forced to abort its mission when an oxygen tank exploded en route to the Moon, NASA decided to take another shot at 13's original landing site in the Fra Mauro highlands. The stakes were high for the entire Apollo program: Two planned Apollo missions had already been canceled due to budget cuts. Another failed mission could end the program.

The scientific highlight of the landing site was the 1,000-foot-wide (305 meters) Cone Crater; geologists hoped the astronauts could find around its rim scattered rocks and boulders that had been blasted out by the impactor. Such samples, excavated from the Moon's depths, could provide vital insight into the early history of the solar system.

Apollo 14 also marked a return to flight for its commander, Alan Shepard. The first American to fly in space, Shepard had been grounded two years after his historic 1961 flight by intense bouts of vertigo due to Ménière's disease, a condition caused by excess fluid in the inner ear. After a successful 1969 surgery to drain the fluid, Shepard was cleared to fly again and added to the Apollo roster. Alongside him were two rookies: Lunar Module Pilot Edgar Mitchell and Command Module Pilot Stuart Roosa.

Though Apollo 14 was a success, it wasn't without some intense troubleshooting of its own. Multiple times, the crew faced technical gremlins that could have forced an abort, only to be saved by the ingenuity of controllers and engineers on the ground — and their own flawless execution.

ABOVE: Apollo 14 astronauts Alan Shepard, Stuart Roosa, and Edgar Mitchell (left to right) pose in front of a Command Module mockup used for water egress training in the Gulf of Mexico.

RIGHT: The Saturn V rocket bursts through the cloud tops, as seen from an aircraft.

Though none of the crew are still alive, transcripts and recordings can still bring the mission back to life. Here's the story of Apollo 14 in their words.

* * *

*Apollo 14 became the first (and only) Apollo mission to have its launch delayed by weather, as an afternoon rain shower on Jan. 31, 1971, pushed back the scheduled liftoff by about 40 minutes. But once the Saturn V rocket engines finally ignited just before 4:03 P.M. EST, the launch and ascent were textbook-perfect.*

**ROOSA:** Liftoff. Clock start.

**SHEPARD:** The clock start?

**ROOSA:** Beautiful!

**RONALD EVANS, LAUNCH CONTROL CENTER:** Clear the tower!

**SHEPARD:** Tower clear. Roll and pitch start. Oh! Look at that —

**GORDON FULLERTON, CAPSULE COMMUNICATOR (CAPCOM), MISSION CONTROL:** Roger, you have good thrust in all five engines.

**SHEPARD:** Beautiful.

**ROOSA:** Go, baby, go!

**MITCHELL:** She's going, she's going. Everything's good.

* * *

*Everything remained good as they lit the final Saturn V stage, breaking free of Earth orbit and setting off for the Moon. But the mission's first critical issue appeared three hours after liftoff, when Roosa attempted to dock the Command Module (CM), named* Kitty Hawk, *with the Lunar Module (LM), named* Antares, *and extract it from inside the final booster stage.*

**ROOSA:** Let's set a record, shall we?

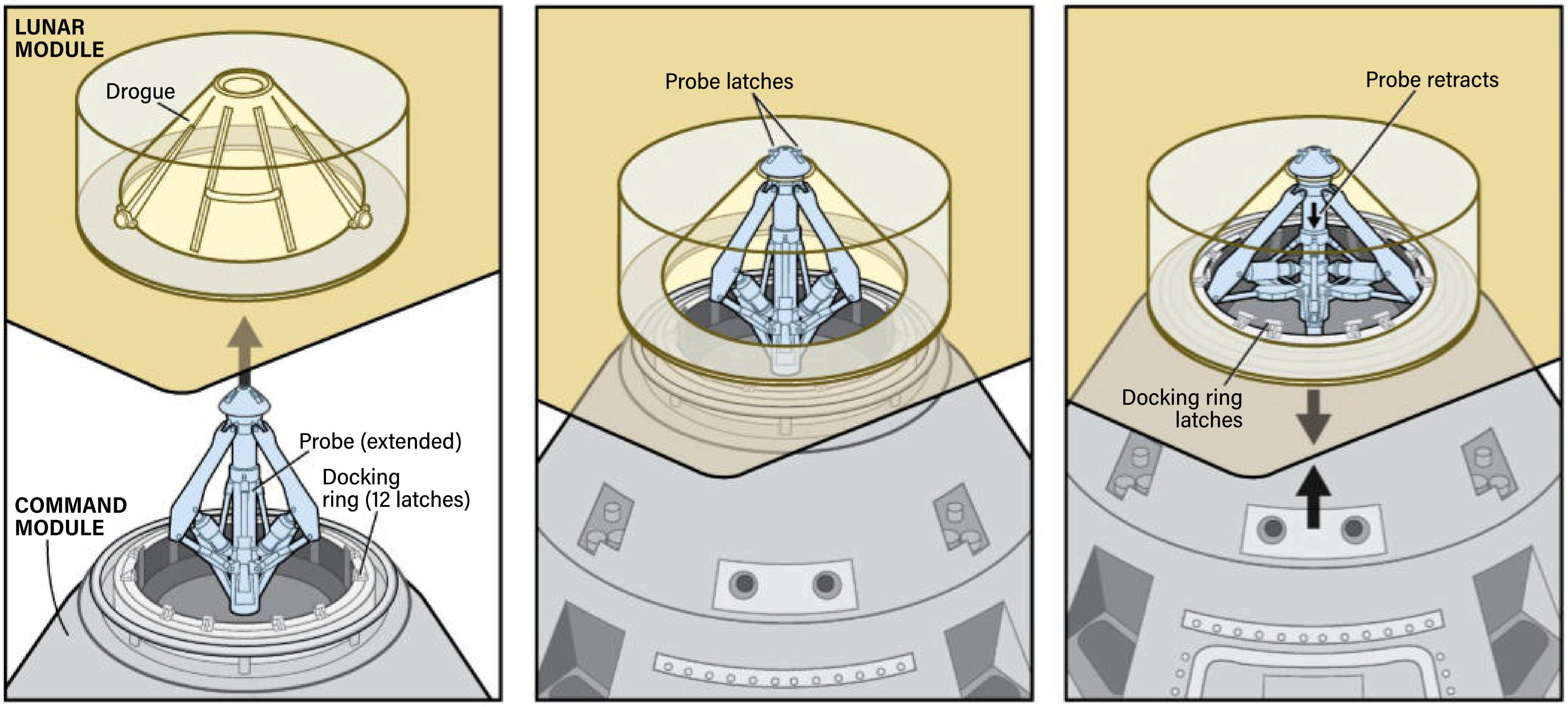
**SHEPARD:** OK.

**ROOSA:** All right.

**MITCHELL:** Slow and easy.

**ROOSA:** OK. And we're going to start.

# CAPTURING THE LUNAR MODULE




To join the Command Module (CM) with the Lunar Module (LM), a probe was mounted to the front of the CM. When the probe was extended, the LM drogue — mounted inside the access tunnel — would guide it to a hole where its latches would grasp it. Then the astronauts would command the probe to retract, pulling the LM and its tunnel against the docking ring attached to the CM. *ASTRONOMY*: ROEN KELLY

**SHEPARD:** OK *[garbled].*
**ROOSA:** Sweaty-palm time.
**MITCHELL:** OK. At 59:50, CMS MODE, AUTO.
**ROOSA:** Sweaty-palm time.
**MITCHELL:** Oh, no, just do it slow and easy.
**ROOSA:** Oh, no. I just keep mumbling that.
**MITCHELL AND ROOSA:** OK.

*The maneuver seemed to come off as planned. But when the CM docking probe made contact with the drogue mounted to the LM, the probe's spring-loaded latches failed to snap into place. Roosa applied forward thrust and made contact a second time, but it still didn't latch.*

**ROOSA:** OK, Houston. We've hit it twice, and sure looks like we're closing fast enough. I'm going to back out here and try it again.
**FULLERTON:** Roger.

*Roosa's third attempt also failed to latch.*

**ROOSA:** Well, there goes the record.
**MITCHELL:** Don't worry about it. Let's get him picked up.
**ROOSA:** OK. Man, we'd better back off here and think about this one, Houston.

*After checking some circuit breakers to ensure electrical power was reaching the probe, Roosa readied for a fourth try. This time, Houston suggested holding forward thrust after contact for three seconds to try and secure the probe latches.*

**ROOSA:** And here we come in again.
**FULLERTON:** Roger.
**ROOSA:** 1, 2, 3, 4 — son of a b----, nothing! OK, Houston. I hit it pretty good and held [forward thrust for] four seconds on contact, and we did not latch.
**FULLERTON:** Roger. We're seeing it all on TV here.
**ROOSA:** *[Sigh.]* S---. *[Garbled]* one more time.

*After a fifth try failed, Houston suggested that Roosa make contact with the drogue, continue to thrust forward, and, even if the probe didn't achieve a "soft dock," retract the probe in the hopes that some of the 12 tunnel latches would snap into place.*

**MITCHELL:** About 6 feet out. *[Pause.]* About — 2 feet.
**ROOSA:** About a foot. Here we go. OK, RETRACT.
**SHEPARD:** Nothing happened.
**ROOSA:** Nothing?
**SHEPARD:** I don't know.

*Suddenly, the latches engaged in a series of loud snaps.*

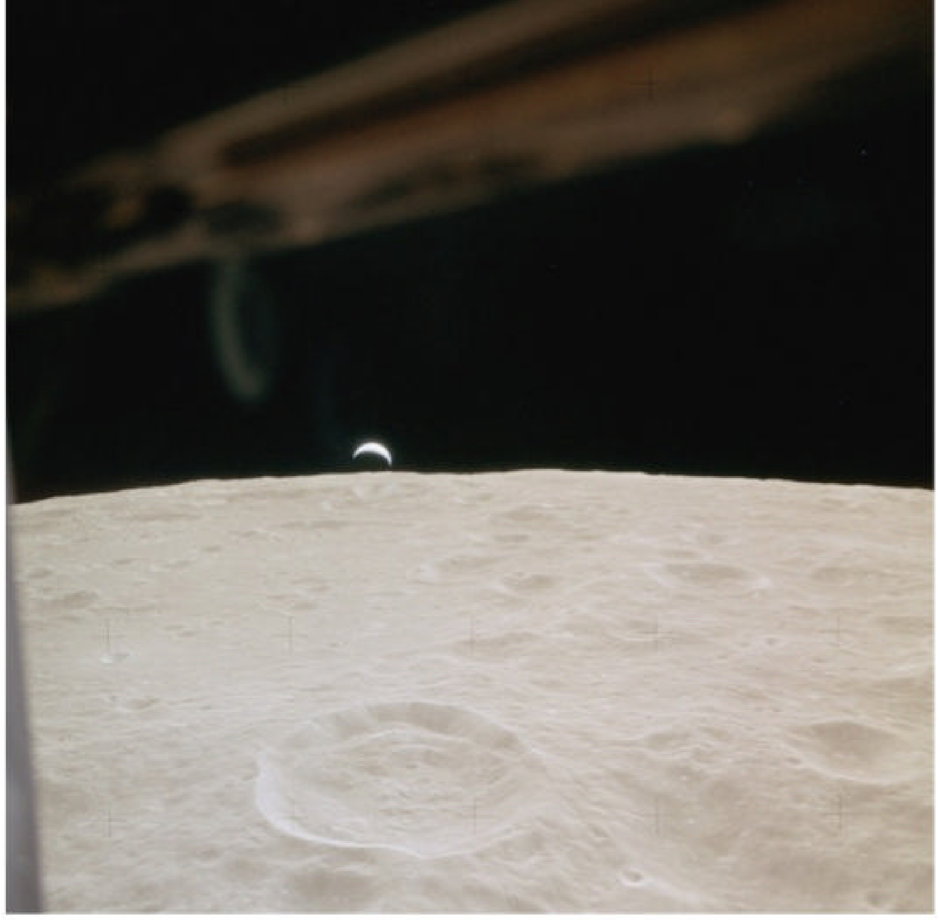
**SHEPARD:** I got — got a barber pole. *[A diagonal-striped "barber pole" status indicator meant an action was in progress.]* We got a hard dock.
**MITCHELL:** We got some [latches], Houston.
**FULLERTON:** Roger.
**ROOSA:** I believe we got a hard dock, Houston.
**FULLERTON:** Outstanding.
**ROOSA:** We got it.

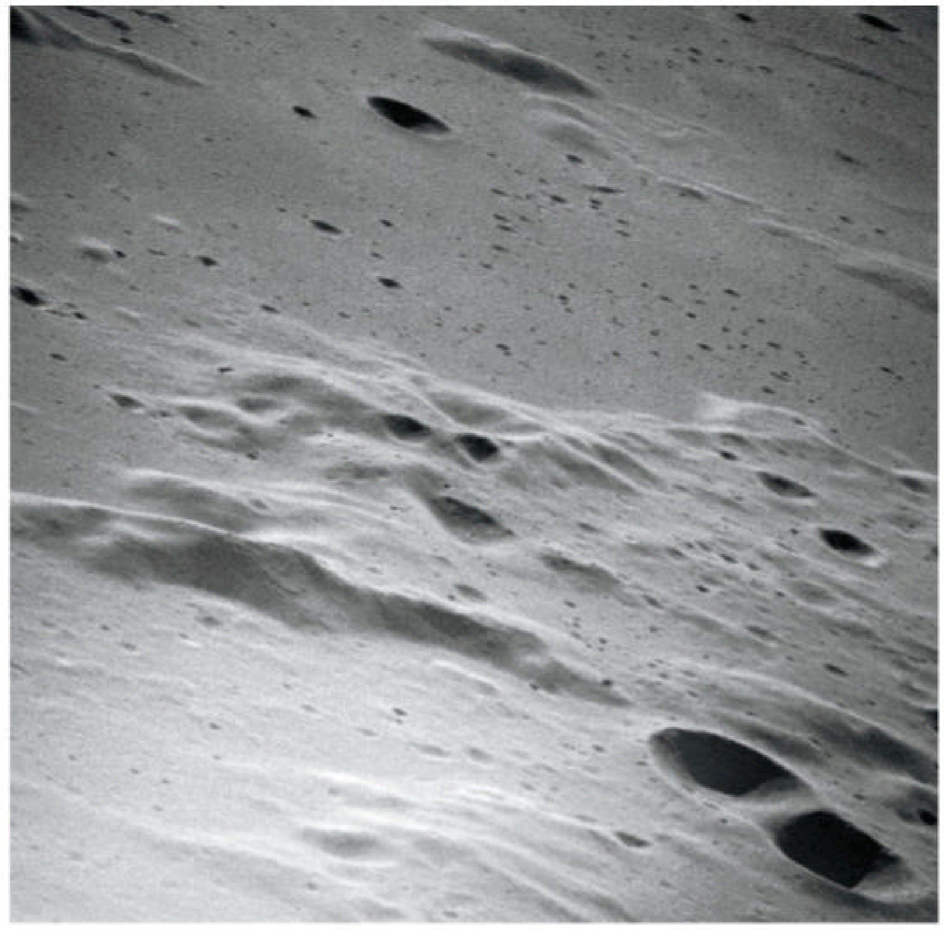
* * *

*After the LM was successfully extracted, the rest of the outbound journey was uneventful, and Apollo 14 slipped into lunar orbit early on the morning of Feb. 4. Late that night,* Antares *undocked from* Kitty Hawk *to begin its descent to the surface.*

*But Mission Control noticed something strange: Their telemetry showed the LM's "abort" button had been activated — even though none of the astronauts reported pushing it.*

**FRED HAISE (CAPCOM):** Ed, could you tap on the panel around the abort pushbutton and see if we can shake something loose? *[Long pause.]*
**MITCHELL:** Yeah, Houston, it just changed while I was tapping there.
**HAISE:** You sure tap nicely.
**MITCHELL:** I'm pretty good at that.





ABOVE: This image of Earth rising over the Moon's limb was taken shortly before Shepard and Mitchell began their lunar descent.

RIGHT: Roosa took this oblique view of the Fra Mauro highlands from lunar orbit.

**HAISE:** OK. *Antares*, we'd like to kind of sit here a minute and watch it.

*Evidently, the switch was contaminated — a small chunk of metal was floating around inside it, intermittently shorting the circuit and triggering the abort button. This was a potentially mission-ending problem — if it happened during the descent, the computer would cancel the landing, jettison the descent stage, fire the ascent engine, and lift Shepard and Mitchell back to lunar orbit.*

*With the mission hanging in the balance and just three and a half hours before the landing was set to begin, MIT software engineer Don Eyles devised a way for the astronauts to hack the guidance computer and disable the abort button. Haise radioed the instructions up to the crew.*

The Apollo Guidance Computer used a "verb" and "noun" syntax in its interface that allowed astronauts to input commands and alter values stored in its memory.

**HAISE:** OK. [At four minutes before the descent burn], Ed, we need a VERB 21 NOUN 01 ENTER; 10 10 ENTER; 107 ENTER.

*This modified a flag in the computer's memory that tracked which program the computer was running, changing it from P63 — the descent program — to P70/71, the abort programs. This fooled the computer into thinking an abort was already in progress — preventing it from actually starting an abort if the button was triggered. However, it also disabled several descent routines the computer was supposed to run. Shepard would have to fly the LM manually while Mitchell performed the rest of the fix: disabling the computer's abort-checking, restoring the descent guidance routines, and resetting the flag to the descent program.*

**HAISE:** OK. After ignition at plus 26 seconds on page 6, we need MANUAL THROTTLE UP. *[This instructed Shepard to manually zoom the throttle to maximum.]* […] After we get by THROTTLE UP, it's VERB 25 NOUN 07 ENTER; 101 ENTER; 200 ENTER; 01 ENTER. And this will enable guidance and give you steering at that time. […] OK, the next entry: VERB 25 NOUN 07 ENTER; 105 ENTER; 400 ENTER; 0 ENTER. […] This'll disable [the abort programs] P70, P71. OK, the next entry: VERB 21 NOUN 01 ENTER; 10 10 ENTER; 77 ENTER. […] This gets us [back] into P63 […] which gets us right for landing radar.

*The last command would ensure that the guidance computer was prepared to accept input from the landing radar, which provided crucial altitude information in the latter stages of the landing.*

*With less than 15 minutes before the descent was set to begin, the astronauts were still sorting out the complex sequence with Houston and each other.*

**MITCHELL:** OK, let me read this [back]. At four minutes [before the burn], that goes in. [And then at] ignition plus 26 [seconds], MANUAL THROTTLE [up].

**SHEPARD:** Rog.

**MITCHELL:** And [then] I'll put these other calls in just as quick as I can get them in.

**SHEPARD:** Yes. One right after the other.

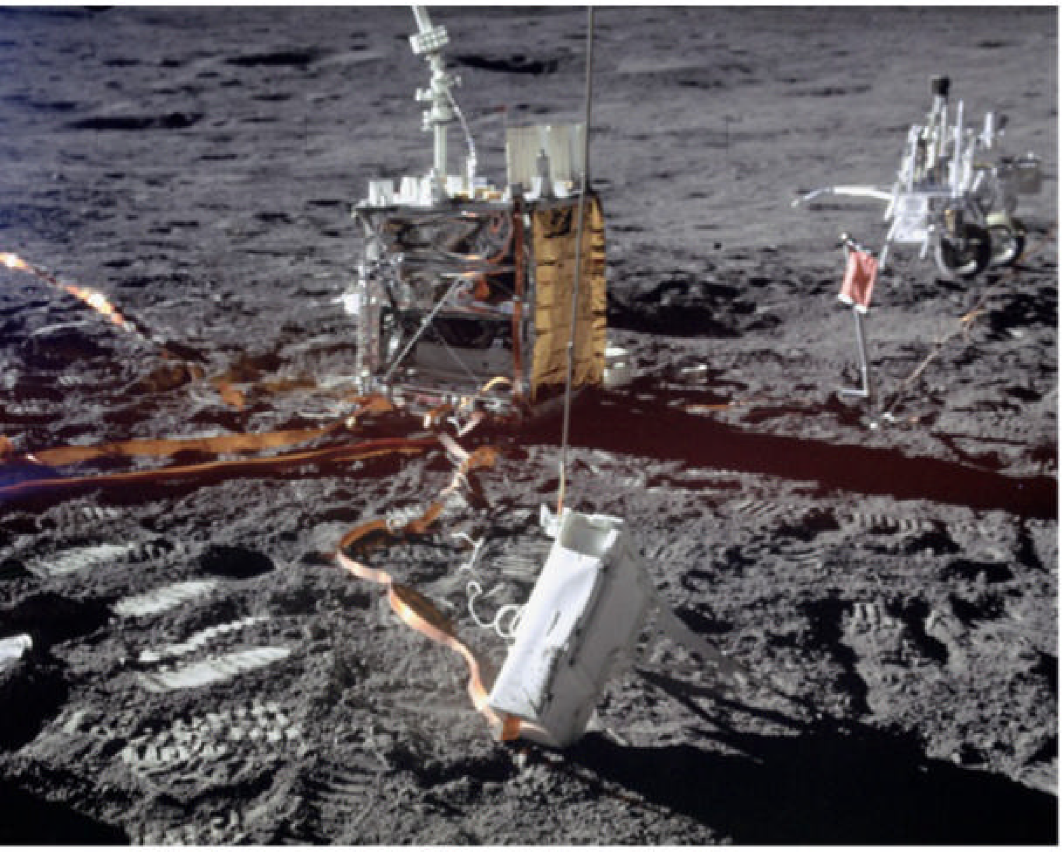
*After 10 final minutes of preparations, the astronauts were ready to begin.*

**SHEPARD:** And *Antares* is standing by for a [Powered Descent Initiation] go. *[Pause.]*

**HAISE:** And *Antares*, Houston. You're go for Fra Mauro.

**MITCHELL:** Good show, Freddo. Thank you.

**SHEPARD:** Thank you. You troops do a nice job down there.



ABOVE: On Shepard and Mitchell's first moonwalk, they deployed the Apollo Lunar Surface Experiments Package (ALSEP). The device in focus in the foreground is a mortar that would fire four rocket-propelled projectiles, generating seismic waves for the package to measure.

RIGHT: Shepard shields his eyes from the Sun in this image taken by Mitchell from inside the LM. Note the red stripes on Shepard's suit, which were added to the commander's suit after public affairs officials at NASA realized how difficult it was to tell Neil Armstrong and Buzz Aldrin apart in the photographs returned by Apollo 11. Apollo 13 commander Jim Lovell was the first to use this convention, but 14 was the first to return photographs from the lunar surface that showed an astronaut sporting the "commander stripes."

**MITCHELL:** That was beautiful.

*Remarkably, the hack went off just as planned, and* Antares *looked back on track. But the drama wasn't over: Unbeknownst to all, the landing radar was stuck in a short-range mode and not feeding any data to the guidance computer. If it didn't work by the time the LM descended to 10,000 feet (3,050 m), mission rules called for an abort. As the descent ran into its fifth minute, Mitchell noticed something was awry.*

**MITCHELL:** Down to 32,000 [feet altitude]. We should be getting landing radar in very soon. […] Come on radar, get the lock on. *[Pause.]* Come on, radar! […] *[Garbled]* can't get the radar in. […]

**HAISE:** OK, six [minutes] plus 40 [seconds] is throttle down, *Antares.*

**MITCHELL:** Roger, Houston. We still have ALTITUDE/VELOCITY lights. *[This meant the landing radar was still not returning any data.]*

**HAISE:** Roger.

**SHEPARD [TO MITCHELL]:** I'll bet they know that.

**MITCHELL:** What?

**SHEPARD:** I'll bet they know that.

*Finally, Houston radioed with a potential solution.*

**HAISE:** *Antares*, Houston. We'd like you to cycle the landing radar breaker.

**MITCHELL:** Cycle the landing radar breaker.

**SHEPARD:** OK, been cycled. *[Long pause.]*

**MITCHELL:** Come on in! *[Long pause.]*

*Then, the radar finally responded.*

**MITCHELL:** OK!

**SHEPARD:** Velocity light [is out]. VERB 57, ENTER. *[This triggered the option for the computer to accept the radar data to inform its guidance.]* How's it look, Houston? *[Pause.]*

**MITCHELL:** Can we accept?

**HAISE:** OK. We'd like to accept the radar.

**SHEPARD:** OK, pro[ceeding]. Converging, pro.

**MITCHELL:** Great. Great. Whew! That was close.

*At eight minutes and 40 seconds into the powered descent burn, the LM rotated to a more upright position, allowing the astronauts to see their landing site, located just over a mile (1.6 km) west-southwest of Cone Crater, for the first time.*

**SHEPARD:** There's Cone Crater. Right on the money.

**MITCHELL:** And there it is!

**SHEPARD:** Right on the money!

**MITCHELL:** Hot damn. Right on the money!

*But as they approached the surface, the astronauts realized that the computer's target was actually slightly off — it was aiming just short of a smaller crater, named Triplet. Shepard decided to take manual control and fly the LM past Triplet to the designated landing site.*

**MITCHELL:** OK, you can move on forward. You're barely crossing North Triplet. Barely crossing North Triplet. Six percent fuel. OK, 150 feet. There's Descent Quantity light [a low fuel indicator].

**SHEPARD:** Starting down, starting down.

**MITCHELL:** OK. It says 90 feet, 4 feet per second, 5 feet per second down. […] Looking great.

**SHEPARD:** OK.

**HAISE:** Sixty seconds [of fuel available].

**SHEPARD:** We're in good shape.

**MITCHELL:** OK. Fifty feet down, 50 feet.

**SHEPARD:** We're in good shape, troop.

**MITCHELL:** Three feet per second. Forty feet. Three feet per second. Thirty. Three feet per second, looking great. Twenty feet. Ten … Three feet per second — contact, Al!

**SHEPARD:** Great, PRO, AUTO, AUTO.

**MITCHELL:** We're on the surface!

**SHEPARD:** OK, we made a good landing!

**HAISE:** Roger, *Antares*.

**MITCHELL:** 413, plus 10,000. *[This stored the craft's landing attitude in the abort guidance computer in case an emergency departure was needed.]* That was a beautiful one.

**SHEPARD:** OK, we're slightly off. We landed on a slope, but other than that, we're in great shape — right on the landing site.

*Shepard and Mitchell had managed the most accurate lunar landing thus far — just 87 feet (27 m) from the target. Still, as they surveyed the surrounding craters and ridges, they struggled to get their bearings.*

**MITCHELL:** OK Houston, the undulations are far too complex for me to try to describe them right now. […] Suffice it to say that I think there is more terrain, more relief here, than we anticipated from looking at the maps.

**SHEPARD:** There's a hell of a lot of relief inside the cabin, I'll tell you that.

* * *

*On the first of their two planned excursions — or extravehicular activities (EVAs) — Shepard and Mitchell stayed within about 700 feet (213 m) of the LM and deployed a package of instruments that included seismic experiments, solar wind monitors, and a magnetometer.*

Mitchell studies the traverse map to figure out where he and Shepard are as they trek toward Cone Crater.

Cone Crater is by far the tallest feature near Apollo 14's landing site, but it didn't necessarily appear dramatic from the ground. In this image, it's the gently sloping feature on the right. Though the crater is off in the distance, the lack of atmospheric haze on the Moon makes it blend in with much closer, gentler undulations.

*On their second day on the Moon, Shepard and Mitchell set out to reach the rim of Cone Crater — more than a mile (1.6 kilometers) away and 300 feet (90 m) higher than their landing site. A boulder field identified from satellite photos directly along the south crater rim was expected to contain the deepest — and therefore the oldest — ejecta from the crater. But navigation wasn't easy. The undulations that Mitchell had described gave him the sense of being lost in a field of sand dunes, even as the slope got steeper.*

**SHEPARD:** Well, we haven't reached the rim yet.

**MITCHELL:** Oh boy, we got fooled on that one. I'm not sure that was Flank [Crater] we were at a minute ago, either. *[Heavy breathing.]* Wait a minute — yes, it is. The rim's right here. That's the uh, that's the east [ridge], uh … *[Heavy breathing.]* … Little shoulder running down from the Cone. That's Flank over there. *[Heavy breathing.]* We're going to hit it on the south side. We'll have to move on around of it. This looks like easy going right here. *[Heavy breathing.]* See, there's the boulder field that shows in the photograph — it's right up ahead of us. […]

**HAISE:** OK, Al and Ed. They'd like you to take another stop here.

**MITCHELL:** OK. *[Heavy breathing.]* We're really going up a pretty steep slope here.

**HAISE:** Yeah, we kind of figured that from listening to you.

*With time ticking away and more sample collections scheduled on the return trip, Shepard suggested abandoning the attempt to scale Cone Crater and settling for sampling some of the nearby boulders, but Mitchell lobbied to press on.*

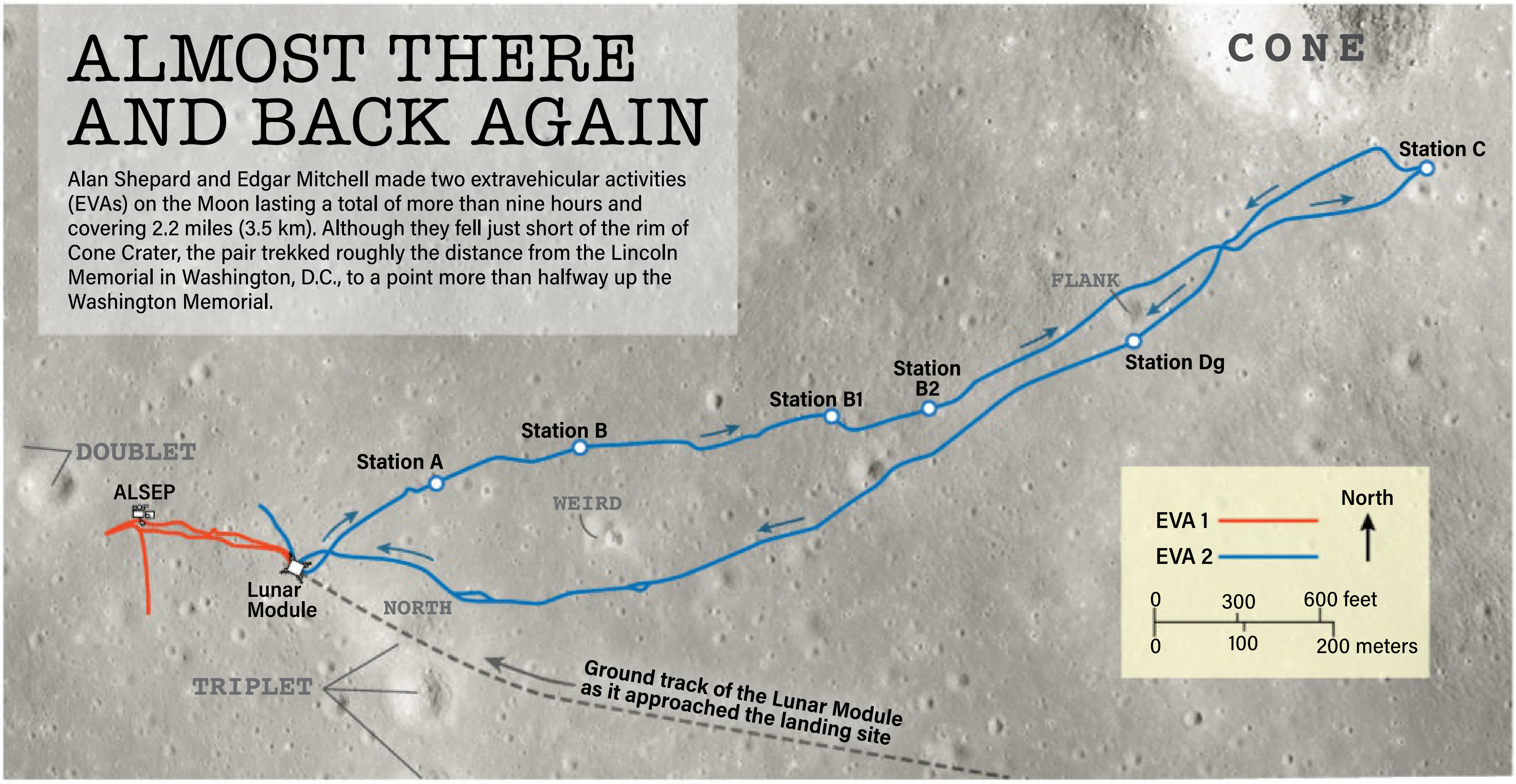
**SHEPARD:** And what I'm proposing is perhaps we use that [boulder field] as the turnaround point. It seems to me that we spend a lot more time in traverse if we don't, and we don't get very many samples. […] I think, Freddo […] the best thing for us to do is to get up here and document samples of what I feel pretty sure is Cone ejecta. […]

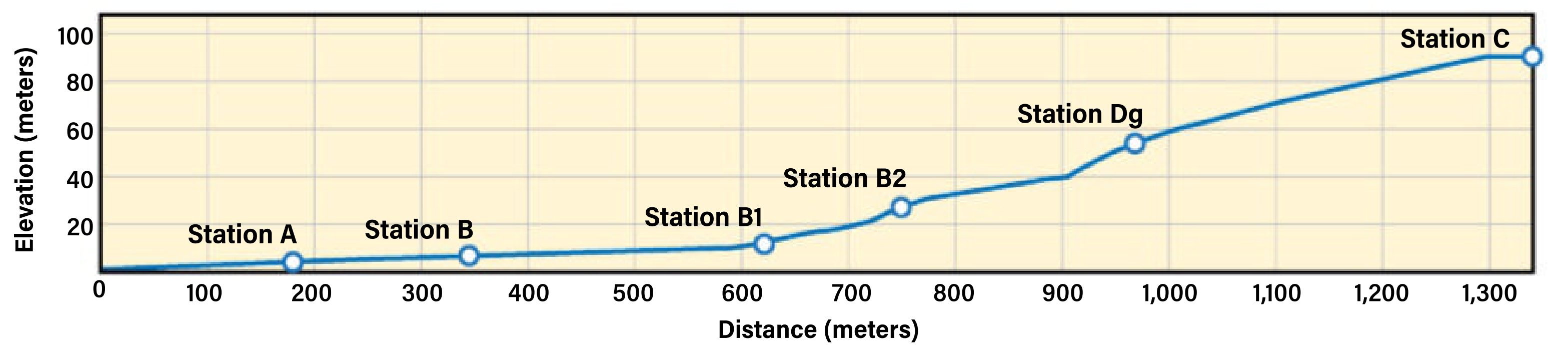
**HAISE:** Roger, Al.

**SHEPARD:** *[referring to two nearby boulders]* Well, let's head for these two babies up here. *[Long pause.]*

# ALMOST THERE AND BACK AGAIN

Alan Shepard and Edgar Mitchell made two extravehicular activities (EVAs) on the Moon lasting a total of more than nine hours and covering 2.2 miles (3.5 km). Although they fell just short of the rim of Cone Crater, the pair trekked roughly the distance from the Lincoln Memorial in Washington, D.C., to a point more than halfway up the Washington Memorial.




*ASTRONOMY*: ROEN KELLY, AFTER THOMAS SCHWAGMEIER AND ERIC JONES. BASEMAP IMAGE: NASA/GSFC/ARIZONA STATE UNIVERSITY

**MITCHELL:** Hey, Al?

**SHEPARD:** Yeah.

**MITCHELL:** I'd, uh … *[Pause.]* No, let's keep going around this crater, but … *[Pause.]* Think that's right here.

**SHEPARD:** *[Sounding skeptical.]* Well, maybe. I thought we'd get those boulders up there, Ed. They —

**MITCHELL:** *[Quickly.]* Yup.

**SHEPARD:** — undoubtedly came from —

**MITCHELL:** Yeah, let's head right for that boulder field at the top. I think we'll be where we want to be.

**SHEPARD:** Right here.

**MITCHELL:** Pardon?

**SHEPARD:** Right *here*.

**MITCHELL:** Yeah, right — clear on up at the top, you mean.

**SHEPARD:** No.

**MITCHELL:** Huh?

**SHEPARD:** I don't think we'll have time to go up there.

**MITCHELL:** Oh, let's give it a whirl! Gee whiz, we can't stop without looking into Cone Crater!

**SHEPARD:** Well …

**MITCHELL:** *[Garbled]* everything if we don't get there.

**SHEPARD:** I think we'll waste an awful lot of time traveling and not much documenting.

**MITCHELL:** Well, the information we're going to find, I think, is going to be right on top. […] Freddo, how far behind our timeline are we?

**HAISE:** OK. The best I can tell right now … about 25 minutes down, now.

**MITCHELL:** OK.

**SHEPARD:** We'll be an *hour* down by the time we get to the top of that thing. You got six samples.

**MITCHELL:** Well … I think we're going to find what we're looking for up there.

**HAISE:** OK, Al and Ed. In view of your assay of where your location is and how long it's going to take to get to Cone, the word from the Backroom is they'd like you to consider where you are [to be] the edge of Cone Crater. *[Pause.]*

**MITCHELL:** [I] think you're finks! *[Long pause.]*

**HAISE:** OK. That decision, I guess, was based on Al's estimate of another, at least, 30 minutes and, of course, we cannot see that from here. It's kind of your judgment on that.

*Mitchell had prevailed for the moment. But as the slope leveled off and the edge of the crater remained elusive, Houston finally called time on their climb.*

**MITCHELL:** This big boulder right here [on the map], Al, which stands out bigger than anything else — ought to be — we ought to be able to see it.

**SHEPARD:** Well, I don't know what — the rim is still way up there, from the looks of things.

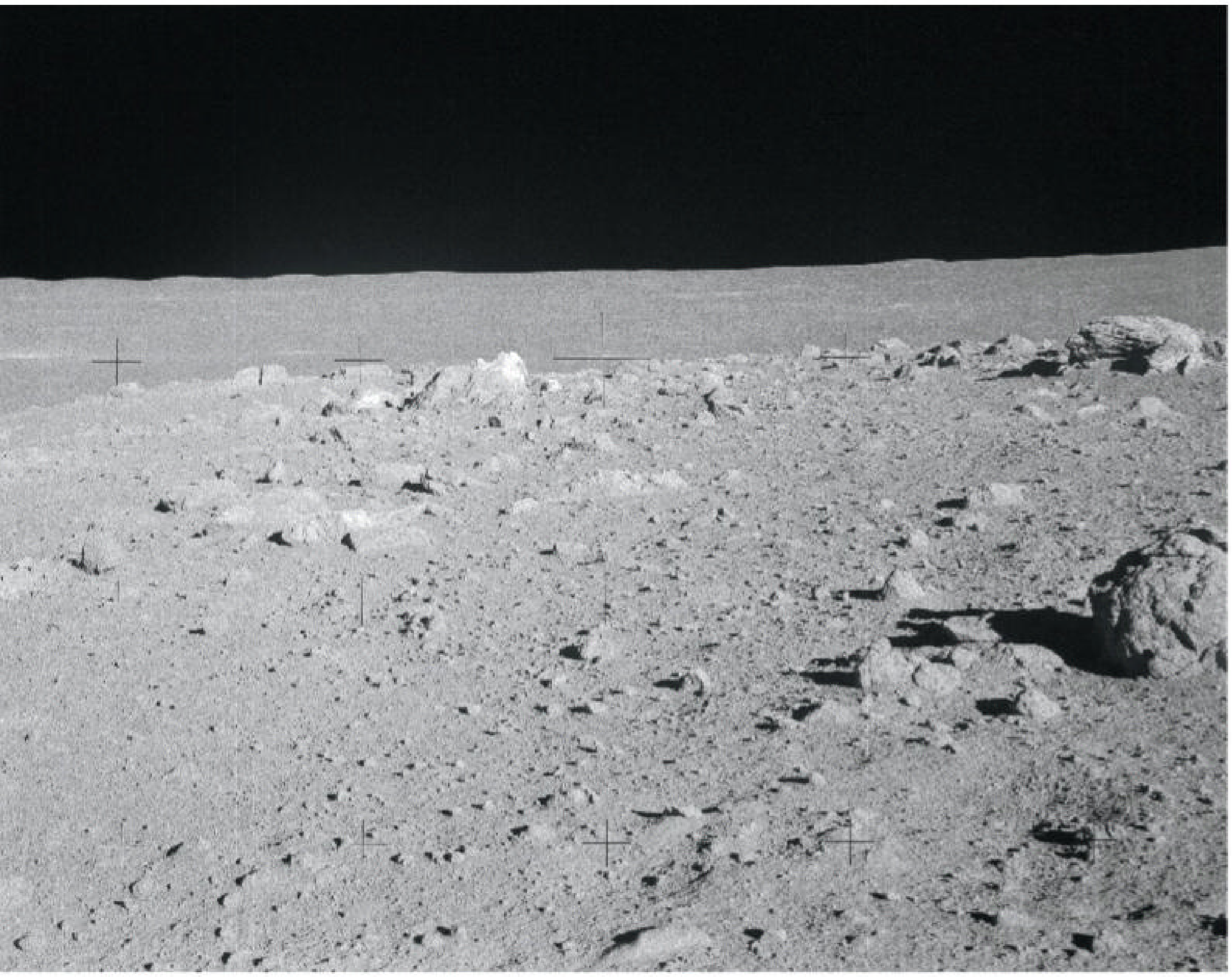
**HAISE:** And, Ed and Al, we've already eaten in our 30-minute extension and we're past that now. I think we'd better proceed with the sampling and continue with the EVA.

**MITCHELL:** OK, Freddo.

**SHEPARD:** OK. We'll start with a pan from here. I'll take that.

**MITCHELL:** All right, I'll start sampling.

*In fact, Shepard and Mitchell were only*



LEFT: The "big boulder" that Mitchell was trying to find near the rim of Cone Crater was actually in plain sight — another indication of how difficult it was to navigate on the Moon. In this image, it's the bright white rock just left of the center of the frame. It's now known as Saddle Rock.

BELOW: Later, the astronauts went over to collect samples from Saddle Rock. Mitchell took this picture, leaving his hammer in the frame for scale.

ABOVE: As *Antares* lifts off, its ascent engine blasts pieces of gold foil off the descent stage and leaves the U.S. flag swinging on its pole.

RIGHT: *Kitty Hawk* splashes down at 3:04 P.M. CST on Feb. 9, 1971, in the South Pacific, about 880 miles (1,420 km) south of American Samoa.

*about 65 feet (20 m) from the rim of Cone Crater. "We just didn't realize how close," Mitchell later said. "It was just out of sight across the next rise a few yards away."*

* * *

*Before the pair clambered back into the LM for the final time, Shepard had one last trick up his sleeve: a specially prepared golf club and two golf balls that he had brought with him to take the most famous bunker shot in the solar system. (See "Apollo 14 in 3D" on page 40.)*

*The Apollo 14 crew splashed down Feb. 9 in the South Pacific and was recovered by USS* New Orleans. *In the end, Shepard and Mitchell gathered 94 pounds (43 kilograms) of lunar samples that would shed light on the early history of the Moon. But on top of the invaluable science, the mission showed that NASA and the Apollo program were back in business.*

**Mark Zastrow** *is senior editor of* Astronomy.

# SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

On May 26, the Moon will take on a brilliant orange-red hue during an early-morning lunar eclipse. STEPHEN RAHN

## OBSERVING HIGHLIGHT

**MERCURY** and **VENUS** come within 24' of each other the evening of May 28. The pair is visible for an hour after sunset.

## MAY 2021

# The morning Moon turns red

Planetary action is picking up again, with three rocky planets — Mercury, Venus, and Mars — easily visible in the evening sky. Jupiter and Saturn feature in the predawn sky. And the western half of the U.S. enjoys a fine total lunar eclipse on May 26.

We begin our tour of the spring skies with **Mercury** and **Venus**, both in Taurus the Bull. They are visible soon after sunset. With the addition of Mars higher above the horizon in Gemini, the trio offers a range of observational treats.

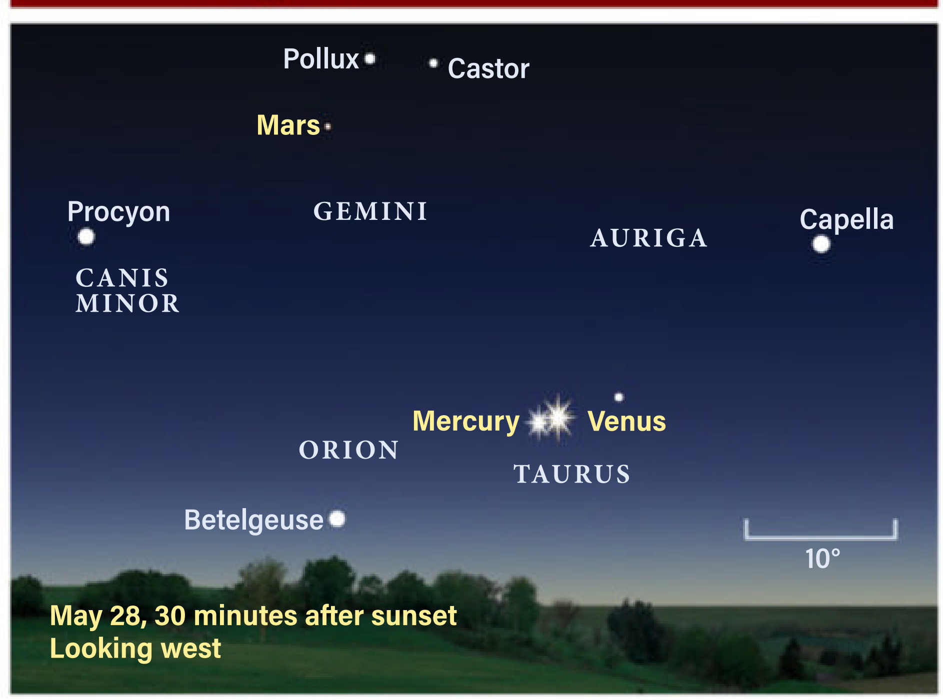
Mercury puts on its best evening show of the year this month. It appears soon after sunset on May 1, less than 5° below the Pleiades (M45) star cluster. Mercury is easy to find, shining at magnitude –1.2. The same day, Venus is just over 5° directly below Mercury and, although brighter, is a tricky target in bright twilight. See if you can spot Venus 30 minutes after sunset — it stands 2° high and shines at magnitude –3.9. The planet quickly sets, so you'll need a clear western horizon to see it.

During the first week of May, both planets' visibility improves dramatically. On May 2, Mercury lies 3° south of the Pleiades — a gorgeous sight in 7x50 binoculars. Its faster pace means it is pulling away from Venus, now 6° lower. Through a telescope, Mercury's tiny disk is 77 percent lit, spanning 6".

The Moon and Venus are stunningly close after sunset on May 12, just one day after New Moon. Venus stands 1.1° northwest of our satellite. Hold your pinky finger at arm's length and it almost fills the gap between them. (Note: Venus is occulted by the Moon the morning of May 13 for observers in some parts of New Zealand).

Grab binoculars to see the Hyades star cluster 4° left of the Moon. In twilight, Aldebaran (not part of the cluster) pops out first, followed by the dimmer stars in the Hyades. The region

**Twilight trio**




Mercury and Venus spend May together in Taurus the Bull. They sit closest together on the 28th, while Mars stands above them in Gemini. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

sets an hour after sunset. Find a clear western horizon to view it.

The following evening, the Moon has moved up to join Mercury — they're 3.1° apart and the planet has faded to magnitude 0.1. They remain above the horizon an hour longer than Venus, so the darker sky background enhances the view — particularly of earthshine on the Moon.

Mercury reaches its greatest eastern elongation on May 17, when it stands 22° from our star. It's the steepness of the ecliptic with respect to the evening horizon that makes this Mercury's best evening apparition for the year. A telescope will reveal an 8"-diameter disk that is 35 percent lit.

Both inner planets continue their race across Taurus. For most of the month, Mercury stays ahead, but its easterly trek slows dramatically in the second half of May. On May 20, Venus stands 7° below Mercury. By May 23, when Mercury reaches a location between the horns of the Bull (Elnath and Alheka), they're 5° apart. The two planets are closest five days later, on May 28, when they stand 24' apart and set just over an hour after the Sun. Mercury is much dimmer at magnitude 1.9 and best spotted using binoculars in the bright twilight.

A telescope that can fit a Full Moon within its field of view will comfortably capture both planets at once. Mercury's disk spans 11" and is 12 percent lit. Venus shows an almost full phase but, due to its greater distance across the solar system, spans only 10" — although the planet is physically much larger than Mercury.

Following their close conjunction, Venus

— *Continued on page 38*

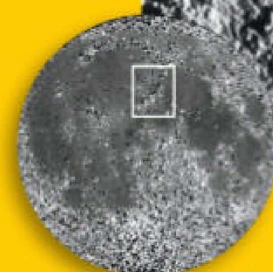
## RISING MOON | Climb every mountain

**A HALF MOON** is a wonderfully detail-packed world of dramatic contrasts. Look on the 18th to find a grand range of mountains straddling the middle of the disk north of the equator. The lunar Apennines are quite rugged compared to the smooth plains of frozen lava to the east. Their long shadows at sunrise tell us they thrust upward 3 miles. Find their black sawtooth shape reaching for the nightside, then come back every 10 minutes to watch the shadows grow shorter and shorter. We're seeing the effects of sunrise on our sister, Luna. Gently curving to the north and east, the spine of the Apennines turns into the Caucasus. In the other direction, they continue into darkness but will be fully visible on the 19th.

Three decades after Galileo's inaugural observation, lunar cartographer Johannes Hevelius published a map using names inspired by the layout of Europe's great mountain ranges. He named this range for the earthly Apennines, which form the backbone of Italy. Of the nearly 300 features Hevelius labeled, only 10 mountains and ranges remain on maps today.

A mere 100 years ago, it would have boggled the minds of observers to hear that the mountain chain is but a small section of a vast bowl 750 miles across, formed when a small protoplanet slammed into the young Moon. The Imbrium basin filled with lava from the Moon's molten interior millennia later. Look closely along the shoreline to detect partially filled craters and blocks of rock collapsed away from the wall. Out on the smoother plains, wrinkle ridges formed wherever material was squeezed horizontally. These gently sloping buckles are visible only at low Sun angles.

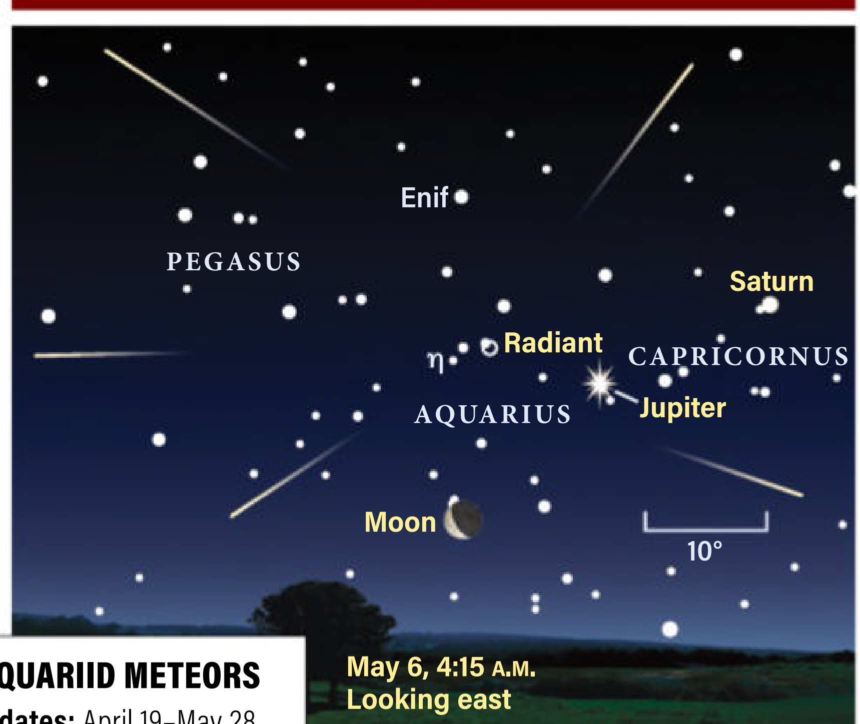
**Apennine Mountains**

The 3-mile-high lunar Apennines take their name from the earthly mountain range in Italy. *CONSOLIDATED LUNAR ATLAS*/UA/LPL. INSET: NASA/GSFC/ASU

## METEOR WATCH | Early morning springtime shower

**Eta Aquariid meteor shower**




Although the Eta Aquariids peak late May 5, the radiant won't rise until early in the morning on May 6.

**ETA AQUARIID METEORS**

**Active dates:** April 19–May 28
**Peak:** May 5
**Moon at peak:** Waning crescent
**Maximum rate at peak:** 50 meteors/hour

**THE SPRINGTIME** Eta Aquariid meteor shower is active from April 19 through May 28, peaking late on May 5. This coincides with a 24-day-old Moon, so conditions are favorable during the early hours of May 6. The radiant in Aquarius rises three hours before dawn and two hours before the crescent Moon. The 10° to 20° altitude of the radiant in the hour or two before dawn reduces the observable number of meteors below the predicted zenithal hourly rate of 50, but the fast-moving meteors — many with persistent trains — make it worth spending a few hours to see perhaps a dozen good ones.

The Eta Aquariid shower is one of two during associated with debris from Comet 1P/Halley. Earth crosses Halley's orbit in May and again in October, when the Orionids occur.

# STAR DOME

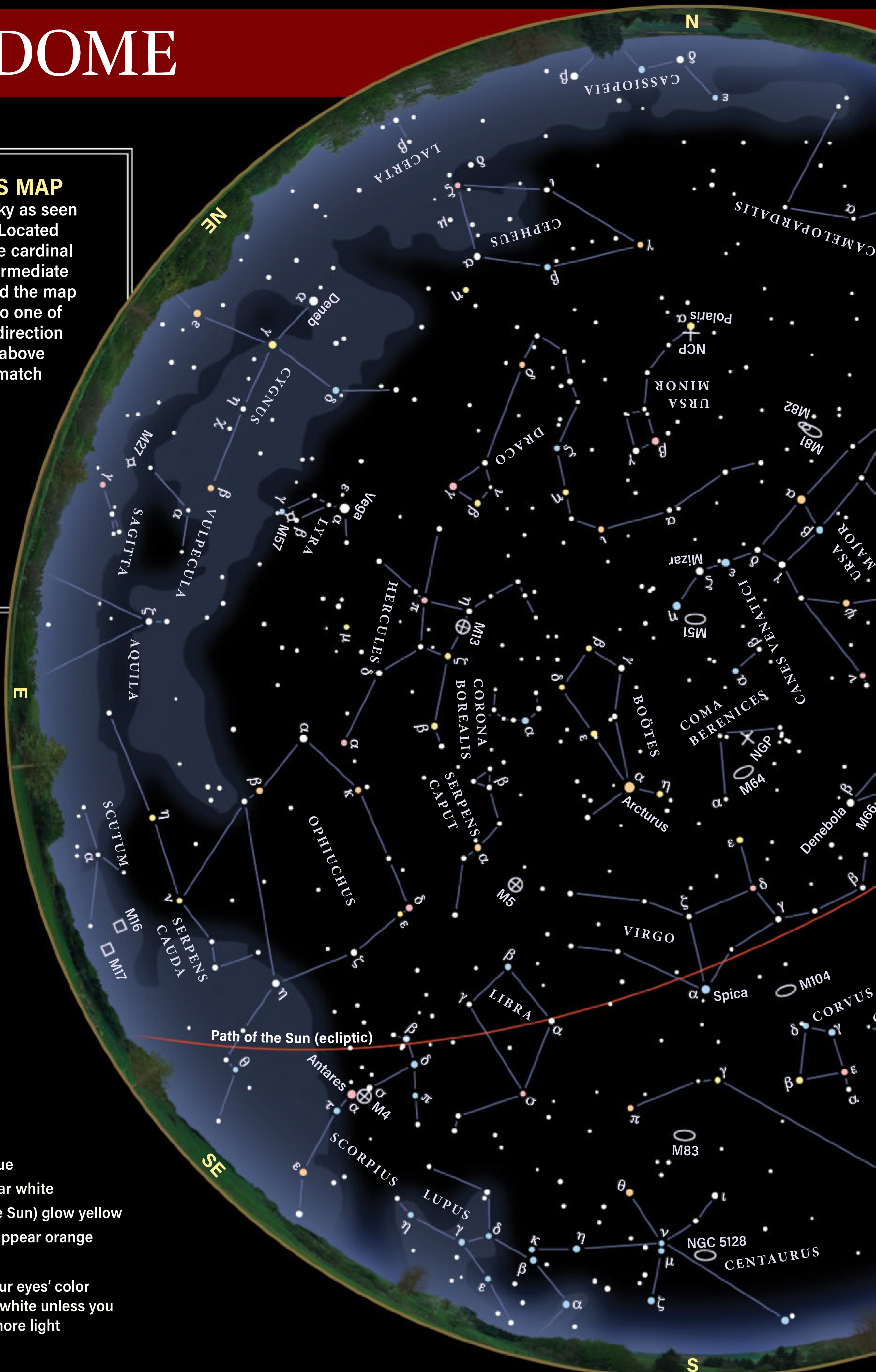
## HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown at midmonth




## MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

## STAR MAGNITUDES

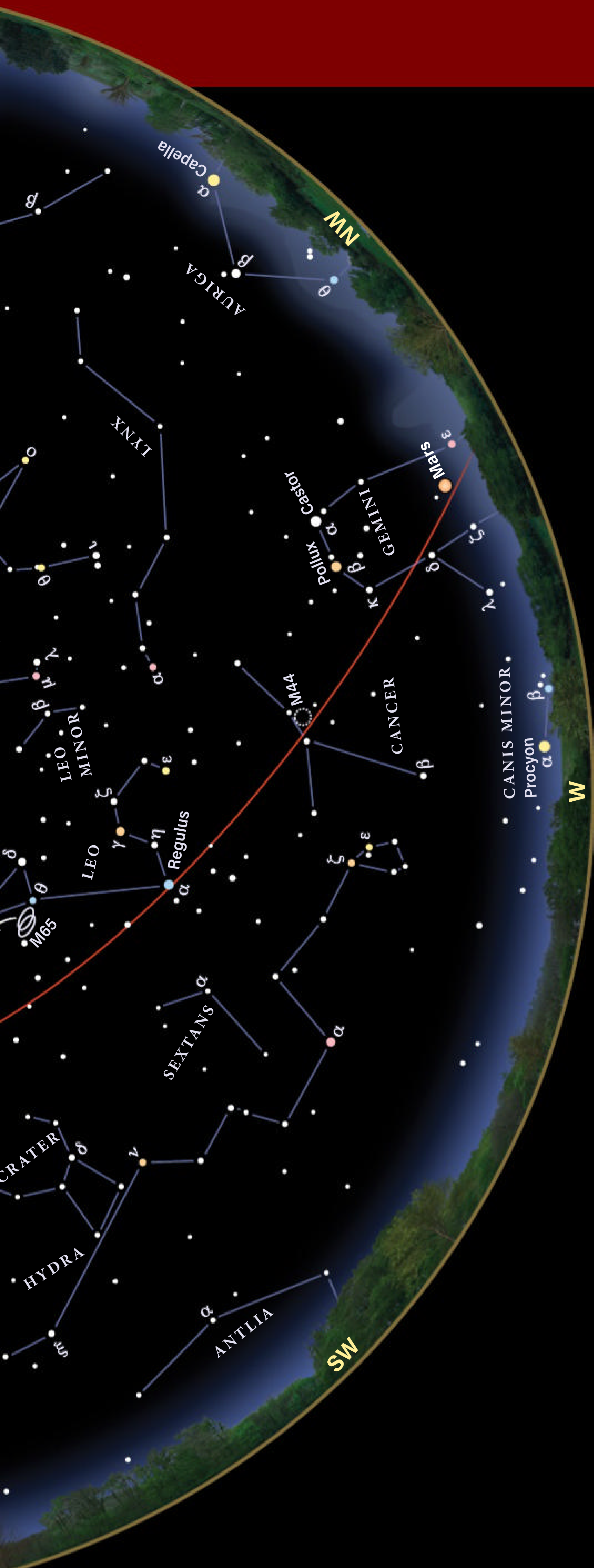
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

## STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**




# MAY 2021

| SUN. | MON. | TUES. | WED. | THURS. | FRI. | SAT. |
|---|---|---|---|---|---|---|
| | | | | | | 1 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| 30 | 31 | | | | | |

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

**Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.**

## CALENDAR OF EVENTS

**3** The Moon passes 4° south of Saturn, 1 P.M. EDT

Last Quarter Moon occurs at 3:50 P.M. EDT

**4** The Moon passes 5° south of Jupiter, 5 P.M. EDT

**5** Eta Aquariid meteor shower peaks

**6** The Moon passes 4° south of Neptune, 2 P.M. EDT

**10** Mercury passes 8° north of Aldebaran, 11 P.M. EDT

**11** New Moon occurs at 3:00 P.M. EDT

The Moon is at apogee (252,595 miles from Earth), 5:53 P.M. EDT

**12** The Moon passes 0.7° south of Venus, 6 P.M. EDT

**13** The Moon passes 2° south of Mercury, 2 P.M. EDT

**16** The Moon passes 1.5° north of Mars, 1 A.M. EDT

**17** Mercury is at greatest eastern elongation (22°), 2 A.M. EDT

Venus passes 6° north of Aldebaran, 7 P.M. EDT

**19** First Quarter Moon occurs at 3:13 P.M. EDT

**23** Saturn is stationary, 4 P.M. EDT

**25** The Moon is at perigee (222,023 miles from Earth), 9:50 P.M. EDT

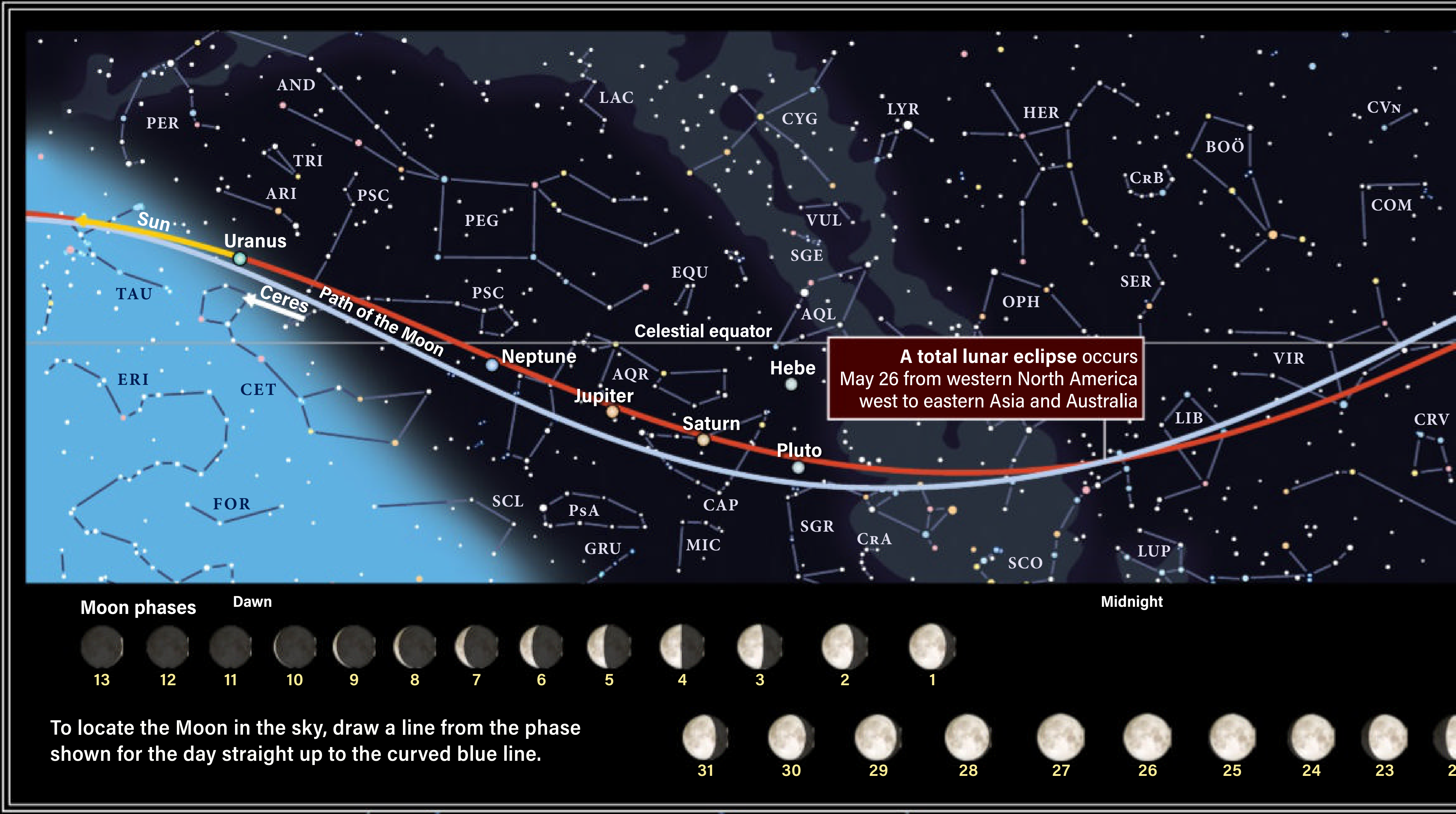
**26** Full Moon occurs at 7:14 A.M. EDT; total lunar eclipse

**29** Mercury passes 0.4° south of Venus, 2 A.M. EDT

Mercury is stationary, 10 P.M. EDT

**30** The Moon passes 4° south of Saturn, 9 P.M. EDT

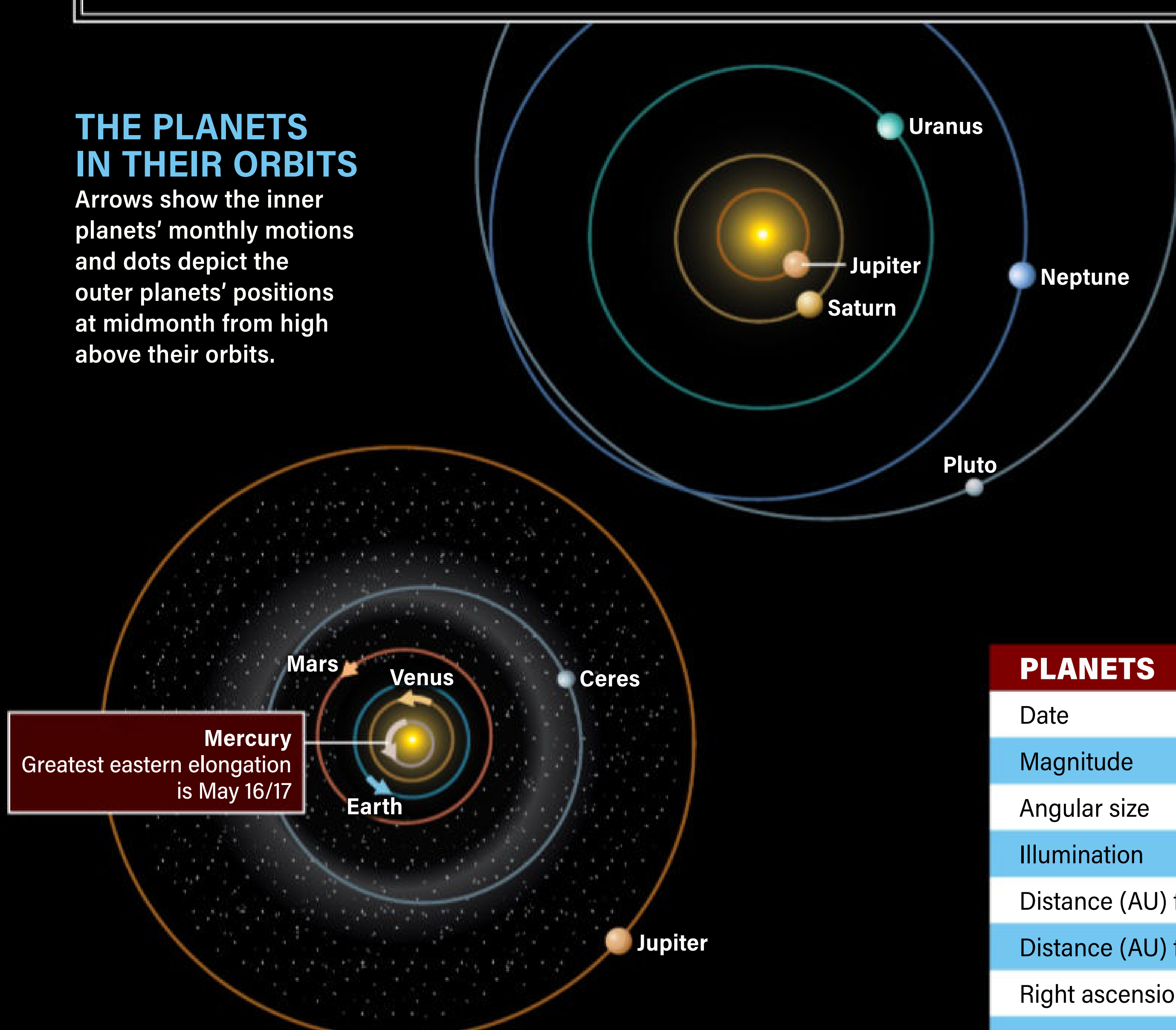
# PATHS OF THE PLANETS




To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

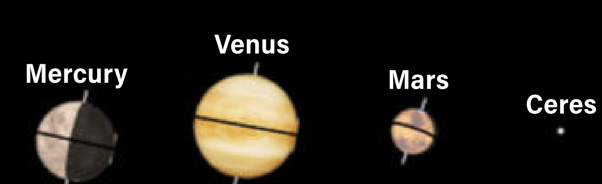
## THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.




## THE PLANETS IN THE SKY

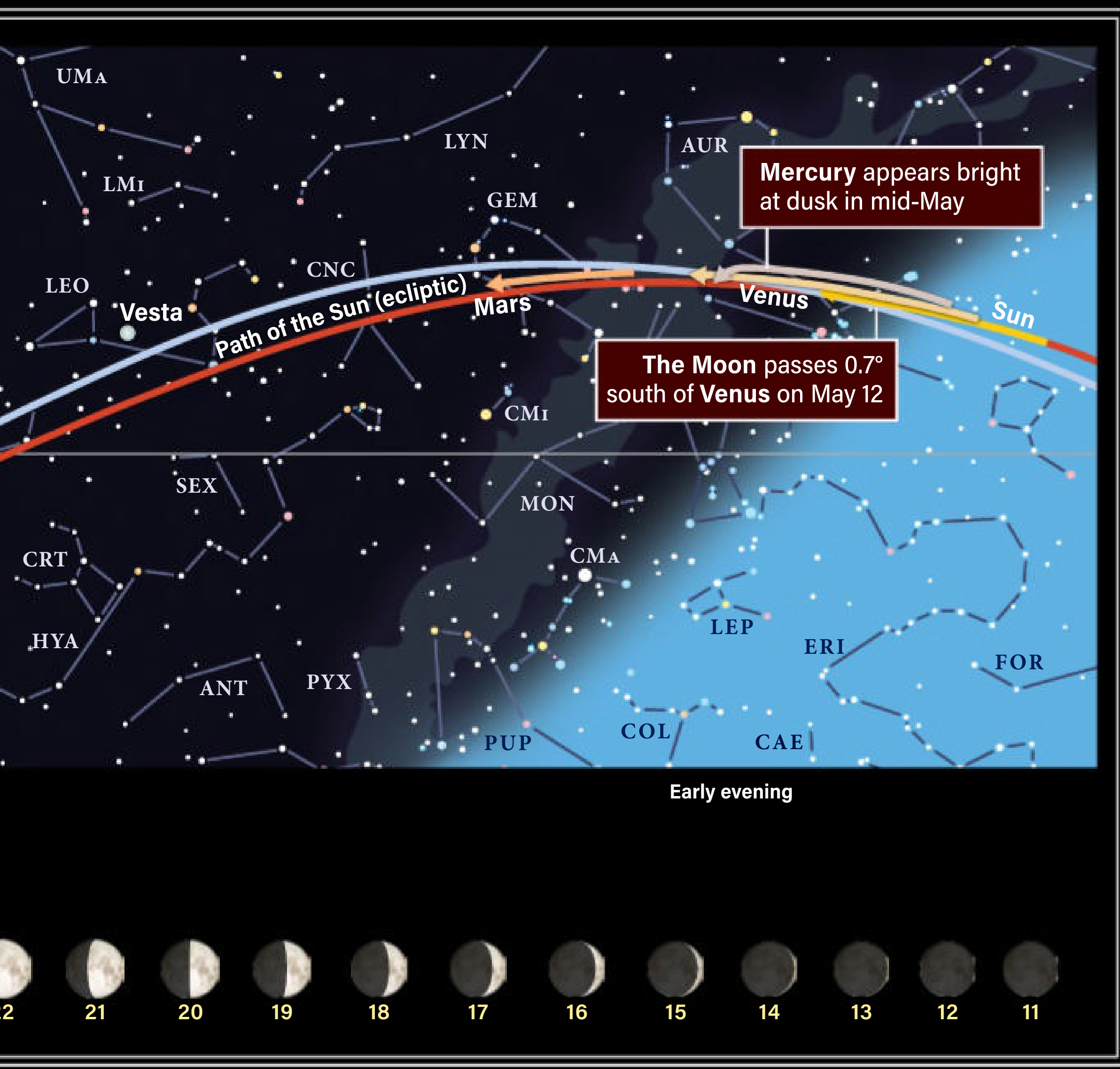
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.




| PLANETS | MERCURY | VENUS |
|---|---|---|
| Date | May 15 | May 15 |
| Magnitude | 0.2 | –3.9 |
| Angular size | 7.6" | 10.0" |
| Illumination | 42% | 97% |
| Distance (AU) from Earth | 0.881 | 1.669 |
| Distance (AU) from Sun | 0.380 | 0.720 |
| Right ascension (2000.0) | 4h57.3m | 4h20.5m |
| Declination (2000.0) | 25°06' | 21°41' |

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

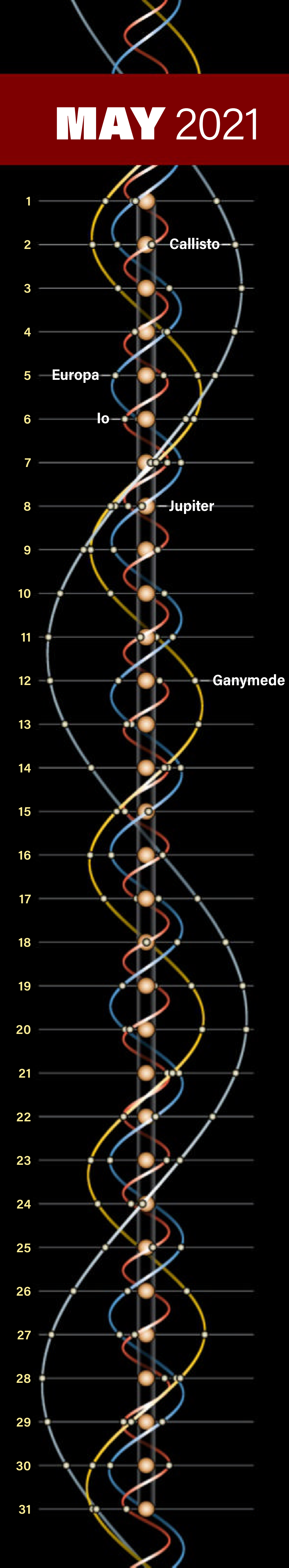
# MAY 2021

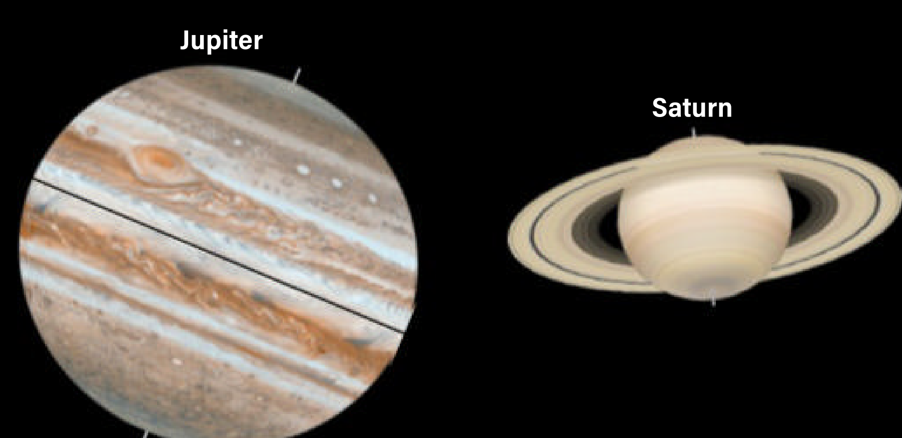


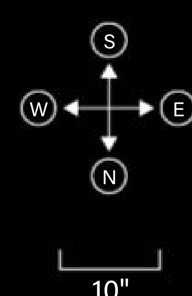

Early evening

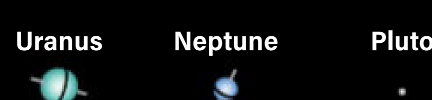

## JUPITER'S MOONS

Dots display positions of Galilean satellites at 5 A.M. EDT on the date shown. South is at the top to match the view through a telescope.




| MARS | CERES | JUPITER | SATURN | URANUS | NEPTUNE | PLUTO |
|---|---|---|---|---|---|---|
| May 15 | May 15 | May 15 | May 15 | May 15 | May 15 | May 15 |
| 1.6 | 9.2 | –2.3 | 0.5 | 5.9 | 7.8 | 15.1 |
| 4.4" | 0.3" | 39.0" | 17.1" | 3.4" | 2.2" | 0.1" |
| 94% | 100% | 99% | 100% | 100% | 100% | 100% |
| 2.130 | 3.799 | 5.052 | 9.723 | 20.738 | 30.391 | 33.800 |
| 1.649 | 2.894 | 5.053 | 9.965 | 19.754 | 29.925 | 34.280 |
| 6h56.2m | 2h09.7m | 22h08.8m | 21h03.3m | 2h35.6m | 23h34.0m | 19h55.0m |
| 24°14' | 6°01' | –12°17' | –17°27' | 14°48' | –4°00' | –22°17' |

# SKY THIS MONTH — *Continued from page 33*

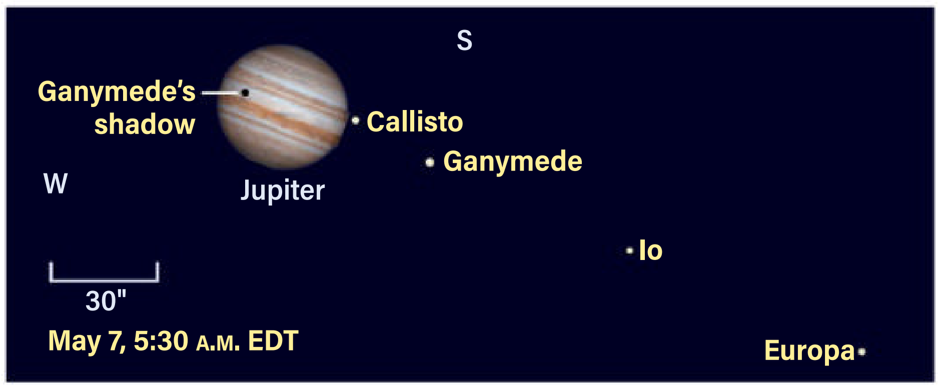
— Continued from page 33

## WHEN TO VIEW THE PLANETS

**EVENING SKY**
Mercury (west)
Venus (west)
Mars (west)

**MORNING SKY**
Jupiter (southeast)
Saturn (southeast)
Uranus (east)
Neptune (east)

### Whose shadow?




On May 7, Ganymede's shadow is already transiting when Jupiter rises. But Callisto is closer to the planet's eastern limb, making it seem like it's responsible for the dark spot. Callisto begins its own transit at 5:48 A.M. EDT.

continues to climb higher, while Mercury sinks back toward the Sun for a June inferior conjunction.

**Mars** crosses the constellation Gemini during May. It begins the month 2.3° due north of 3rd-magnitude Mu (μ) Geminorum, which shares the northwest corner of Gemini with Eta (η) Geminorum, just 2° farther west.

> **3** Three rocky planets — Mercury, Venus, and Mars — grace May's evening skies.

Mars glows at magnitude 1.6 and spans about 5" — so small that surface details are difficult to see visually, rendering it a disappointing telescopic object. It spends May 8 to 10 within 1° of 3rd-magnitude Mebsuta, (Epsilon [ε] Geminorum). When the Red Planet occulted this star in April 1976, just three months before the famed Viking landings, major telescopes observed the event to study the martian atmosphere.

Mars ends the month 5° south of Pollux, Gemini's second-brightest star. By then, the planet's increasing distance from Earth has dimmed it by another 0.1 magnitude.

**Saturn** is a bit fainter than 1st magnitude and rises around 2:30 A.M. local time on May 1. It stands in Capricornus, 1° from Theta (θ) Capricorni. In the last full week of May, Saturn reaches its stationary point 0.6° shy of Theta, then begins retrograde motion. On May 31, Saturn — shining at magnitude 0.4 — rises shortly before 1 A.M. local time. This places the ringed planet 30° high at the onset of twilight, a fine location for telescopic views. It's been many months since good views of Saturn have been available, so check out the disk for any erupting white spots indicative of new storm systems.

Saturn's disk spans 17" at its equator and is 1.5" smaller from pole to pole. Its rings add dramatic width, spanning roughly 40" across the long axis and 11" across the minor axis. The rings' narrower span compared with their appearance last year means the planet's southern polar regions are becoming visible for the first time in eight years. Saturn stands nearly 7° northeast of a Last Quarter Moon on May 3 and 6° northwest of a waning gibbous Moon on May 31.

A few of Saturn's many moons are visible in amateur scopes. Titan is the easiest to see at magnitude 8.4. On May 3, it lies 2.8' due east of the planet. It is south of the planet May 7 and 23, and north of the planet May 15 and 31.

Iapetus is at superior conjunction with Saturn May 6, on its way to eastern elongation and fading as it progresses. The moon has a dark hemisphere that is turning our way, taking it from 11th magnitude near conjunction to 12th magnitude at greatest eastern elongation May 25, when it reaches 8.3' east of Saturn. Tenth-magnitude Tethys, Dione, and Rhea

## COMET SEARCH | Into the distance

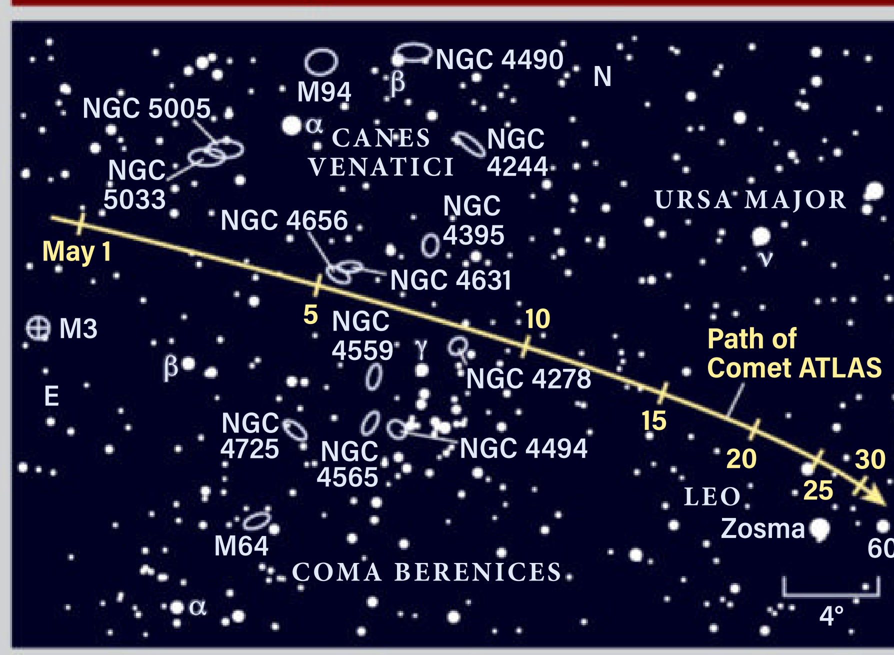
**THIS MONTH** is our last chance to see C/2020 R4 (ATLAS). Next month, we'll hit 7P/Pons-Winnecke at its best, while C/2017 K2 (PanSTARRS) will remain in our sights for the next three years. And with a little luck, a newer, brighter visitor will outdo them all.

Discovered September 12, ATLAS appears similar to a cyclist passing us while we're on foot: We first rapidly turn our gaze to track their motion, then barely adjust to watch them diminish into the distance. ATLAS exited Boötes at 3.5° per night in late April and slows to a 20'-per-night crawl on Leo's back by May's end.

During the first week of May, warm up your observing skills on the compact galaxy M94 in Canes Venatici before dropping 10° south to the fainter and smaller comet. You'll likely need a 10-inch scope at 150x or more to pick up its soft glow.

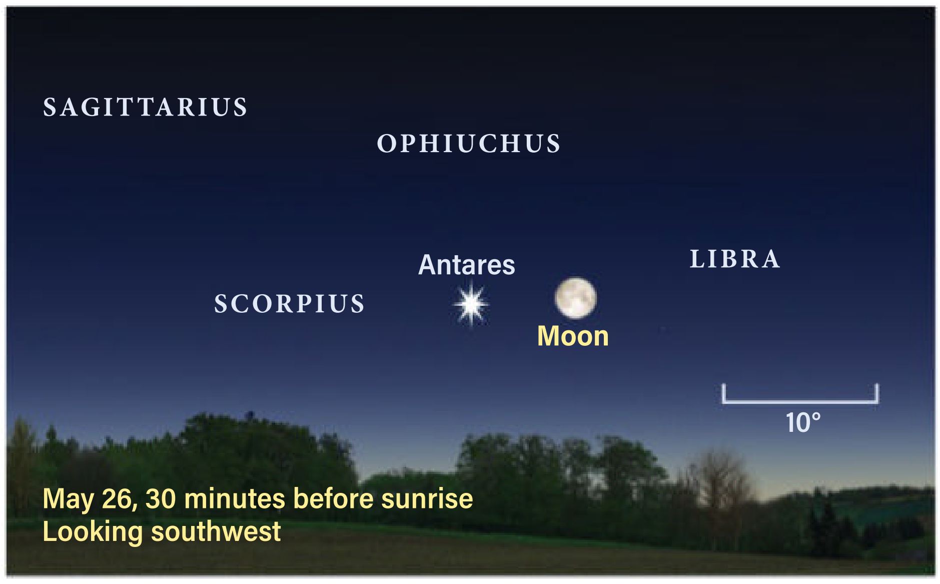
Moonlight puts an end to visual sightings midmonth, leaving the next good look at the comet to our descendants 1,000 years from now.

### C/2020 R4 (ATLAS)




On May 5, NGC 4631 shines at 9th magnitude less than 3° west of Comet ATLAS. The edge-on galaxy NGC 4656 glows at 10th magnitude between the two. You'll find numerous other galaxies of scattered along the comet's path this month.

### Morning Moon eclipsed




Bright Antares sits about 7° southeast of the Moon on May 26 as a lunar eclipse gets underway. The complete event is not visible from the continental U.S.

## LOCATING ASTEROIDS |

### Track asteroids across the Lion

**JOIN ONE OF THE EASIEST** asteroid hunts, already underway high in the south as darkness descends. From the suburbs, you can pop outside with binoculars and catch main-belt asteroid 4 Vesta masquerading as a magnitude 7.5 field star just to the right of Leo's hindquarters.

The only trick is that you'll need more than one evening to positively identify the 300-mile-wide space rock. There are a handful of stars just a little fainter and brighter here, but they won't shift night to night. Place them as dots in a logbook or on paper, and see which one changes compared to the others. By the third evening, you'll catch it in just a few minutes.

Skip the nights from the 18th to the 21st, when the waxing gibbous Moon passes by, causing glare and washing out the background sky.

If you want to see an asteroid move during one observing session, try and catch 29 Amphitrite on May 13 as it gives Leo's luminary a heart attack, almost blocking out Cor Leonis (Regulus). Use a nearby 8th-magnitude field star as a reference; Amphitrite will be three times closer to Regulus. Visit www.asteroidoccultations.com for a list of actual "hits," or occultations, to watch for.

### Heart and tail


Asteroid 4 Vesta offers easy viewing in Leo's hindquarters, while 29 Amphitrite makes a close pass by the Lion's heart.

congregate near Saturn, orbiting every few days and constantly changing relative positions. Enceladus — at magnitude 12 — lies near the edge of the rings and Saturn's glare makes viewing it more of a challenge.

**Jupiter** rises 45 minutes after Saturn and now resides in Aquarius, where it will remain for most of 2021. It starts out the month at magnitude –2.2 and brightens to –2.4 by late May. The gas giant is 30° high at the onset of morning twilight in the last week of May, offering a good chance for clear views of its cloud belts while avoiding some of the blurring effects of our own atmosphere.

Jupiter's disk spans 41" by May 31. This is the start of its main 2021 observing season. With the bright outbreak in the Northern Temperate Belt and the sudden appearance of Clyde's spot, among others, in methane-band images, 2020 offered lots of drama. Regular observers of Jupiter are sure to be watching closely. The gas giant's Galilean moons are on show most nights: Io, Europa, Ganymede, and Callisto provide a constantly changing display and often produce shadow transits, occultations, and eclipses.

**Neptune,** in northeastern Aquarius, rises about an hour after Jupiter. It is best seen in late May, when it's had time to rise higher by the onset of twilight. On May 31, it stands 5.6° east of Phi (ϕ) Aquarii and due south of the Circlet of stars in Pisces. A telescope will show it within 4' of a 7th-magnitude field star. Shining at magnitude 7.8, Neptune is within range of binoculars.

**Uranus** reappears low on the eastern horizon as dawn breaks, 11° below Hamal, the brightest star in Aries the Ram. At magnitude 5.9, Uranus is tricky to spot as the sky brightens. Its observability will improve late next month.

A total lunar eclipse occurs May 26, coinciding with lunar perigee, when the Moon is closest to Earth (222,022 miles). The event is visible across western North and South America, the Pacific Ocean, Australasia, and eastern Asia.

The eclipse occurs near moonset early on May 26 across much of the U.S. In the Midwest, the setting Moon enters Earth's shadow at 4:44 A.M. CDT, with the Moon about 10° above the horizon, amid the stars of Scorpius. The shadow progresses across the Moon as twilight grows. Totality begins at 6:11 A.M. CDT, just as the Moon is setting or shortly after it has disappeared across the Midwest.

Observers in the Mountain and Pacific time zones have better luck. In the Pacific time zone, the partial phase begins at 1:47 A.M., totality lasts from 4:11 A.M. to 4:25 A.M., and the partial phase ends at 5:52 A.M. — after the Moon has set for many locations.

Totality lasts only 14 minutes because the Moon cuts across the northern edge of Earth's shadow. The Moon's northern limb will appear brilliant orange, compared with a duskier southern hemisphere.

***Martin Ratcliffe** is a planetarium professional and enjoys observing from Wichita, Kansas. **Alister Ling**, who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**


Relive the 50th anniversary of Alan Shepard's lunar adventures with stereo images that transport you to the Moon.

BY DAVID J. EICHER AND BRIAN MAY

# APOLLO 14 IN 3D

In this view, the Apollo 14 LM, *Antares*, reflects a circular flare caused by the brilliant sunlight over the Fra Mauro highlands. Shepard and Mitchell said the unusual ball of light had a jewel-like appearance. At the extreme left of the image is the lower slope of Cone Crater. NASA/JSC

IN the wake of the near disaster with Apollo 13, NASA took precautionary plans with the following mission to tighten safety regulations and procedures. The eighth crewed mission in the Apollo program, Apollo 14, was scheduled for a liftoff in late Jan. 1971.

In the U.S., President Richard Nixon was still grappling with the Vietnam War, declaring that the combat mission of American troops would end by the coming summer. The administration's criminal activities, which would ultimately result in the Watergate scandal, were already underway, though as yet undetected. The cultural leaders of the rock 'n' roll movement, the Beatles, had broken up, leaving a wide-open and uncertain future for the leading edge of pop music. The pure idealism of the '60s seemed faded; the hippie culture had subsided and, although no one quite knew it yet, the "me decade" of self-interest was already rolling forward. In the Soviet Union, the space program kept moving, but the momentum for a crewed lunar program was now completely gone.

The crew of Apollo 14 pose in front of their mission badge at the Kennedy Space Center. From left, they are Command Module Pilot Stuart Roosa, Commander Alan Shepard, and Lunar Module Pilot Ed Mitchell. NASA

## Meet the crew

To lead the first Apollo mission of 1971, NASA turned to a wily veteran. Alan Shepard had been the first American in space, making his suborbital flight May 5, 1961, just 20 days before John F. Kennedy's speech calling for a mission to land on the Moon. Shepard, age 47, was born in New Hampshire and had a distinguished career as a naval aviator and test pilot before his Mercury flight in Freedom 7. Now he was slated to be the commander of Apollo 14; this would make him the oldest person ever to walk on the Moon, as well as the only Mercury astronaut to accomplish this feat.

Joining Shepard would be Command Module Pilot Stuart Roosa and Lunar Module Pilot Edgar Mitchell. Shepard's spaceflight experience would be especially valuable: Both Roosa and Mitchell were rookies, having never yet flown in space. Roosa, age 37, was an aeronautical engineer, Air Force pilot, and test pilot. He was born in Colorado and achieved an impressive military record before being chosen as one of NASA's astronaut class of 1966. Mitchell, age 40, was a Navy officer and aviator, test pilot, and aeronautical engineer. Born in Texas, he was also selected in the 1966 astronaut group, and had served in support teams on previous Apollo missions before his assignment to Apollo 14.

The mission's backup crew consisted of Gene Cernan, Ronald Evans, and Joe Engle. (Later, with Harrison Schmitt substituting for Engle, this crew would become the primary one for the final Apollo mission.)

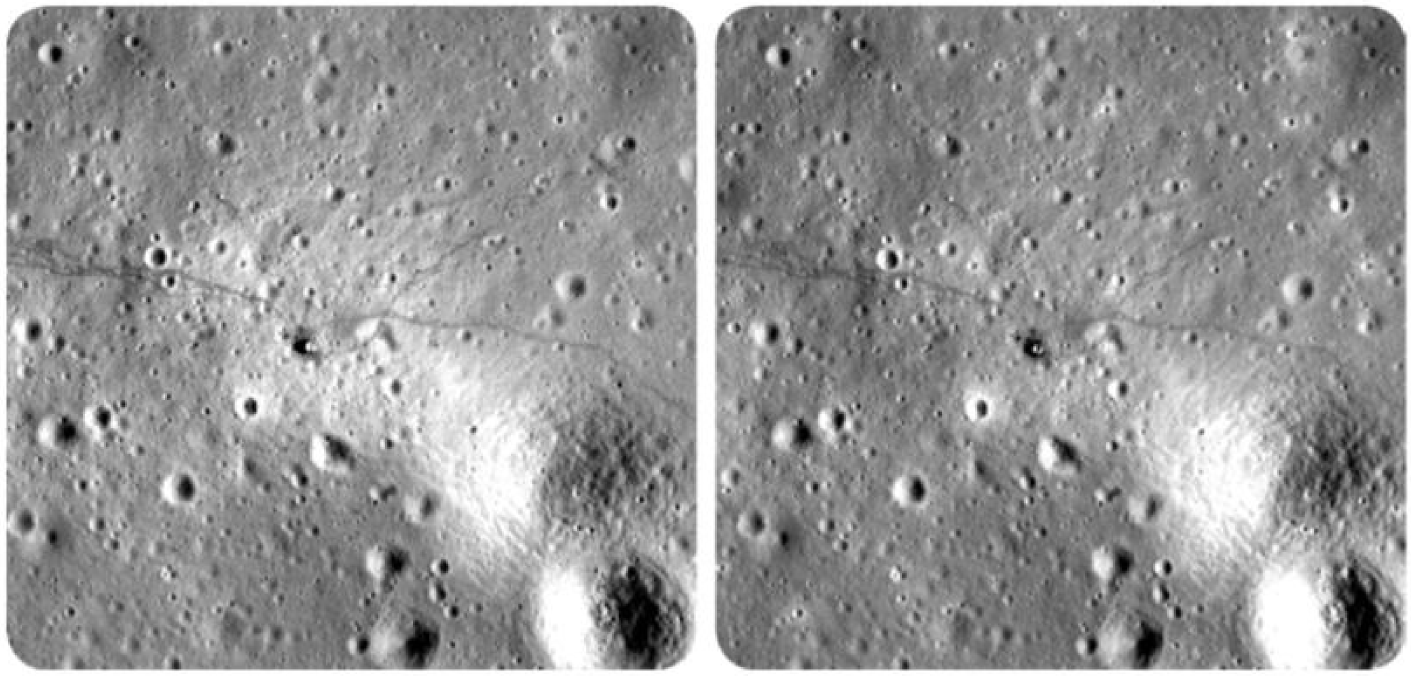
## Changes ahead

Apollo 14's Command/Service Module was nicknamed *Kitty Hawk* and the Lunar Module (LM) *Antares*. Following Apollo 13, NASA engineers modified the electrical power system of the Service Module, attempting to minimize the risk of any further malfunctions. The team redesigned the oxygen tank in which an errant spark had caused the explosion when Swigert switched on the stirring fans. They added a third tank as well. Confidence in the new design was high.

The launch date for Apollo 14 was originally set for Oct. 1, 1970. But Apollo 13 changed the timetable, pushing it back. The new launch date for Apollo 14 was scheduled for Jan. 31, 1971, and the mission was to aim again at the region of Fra Mauro, the area targeted by the aborted Apollo 13. This region of highlands, named after the crater lying within it, consists largely of ejecta from the immense impact that created the nearby Mare Imbrium. Studying this hilly geological area would provide insights on the formation of Mare Imbrium. Furthermore, the debris covering the ejecta was thought to consist of exposed older rocks from deep below. Retrieving them might allow the explorers to uncover some secrets about the Moon's geological history; now the Apollo missions were evolving from simple exploration and wonder at just being on the lunar surface to a deeper and more organized program of scientific studies.

## Bumpy beginnings

The January launch took place right on schedule, despite heavy cloud cover that hung over Kennedy Space Center. With U.S. Vice President Spiro Agnew on hand, along with Spanish Prince Juan Carlos and his wife, Princess Sophia, the Saturn V jumped skyward and quickly



The Apollo 14 landing site in the highlands of Fra Mauro appears in this image made with the Lunar Reconnaissance Orbiter on Nov. 28, 2009. The descent stage of the LM *Antares* is clearly visible, as are tracks made by the small wheeled cart Shepard and Mitchell used to transport equipment and specimens. The width of the image is about 1,138 feet (350 m). NASA/GSFC/UNIVERSITY OF ARIZONA

out of sight into the clouds. The spacecraft achieved Earth orbit, and Shepard separated the Command/Service Module from the Lunar Module and turned the former around for docking.

Then the mission had its first hint of trouble. The astronauts undertook the docking procedure multiple times, having trouble each time completing the maneuver. Finally, after more than an hour and a half, Roosa tried holding *Kitty Hawk* against *Antares* with its thrusters while simultaneously retracting the docking probe. The docking latches took hold, accomplishing the procedure. There was a sigh of relief following the close call — an inability to connect the Command and Lunar Modules was potentially a major problem.

On Feb. 4, Apollo 14 concluded its glide phase over the 240,000-mile (386,000 kilometers) trip to the Moon. Entering lunar orbit, the spacecraft seemed fine. The following day, Shepard and Mitchell climbed into the LM and prepared for their descent to Fra Mauro. Roosa would stay within *Kitty Hawk*, piloting it as it circled the Moon.

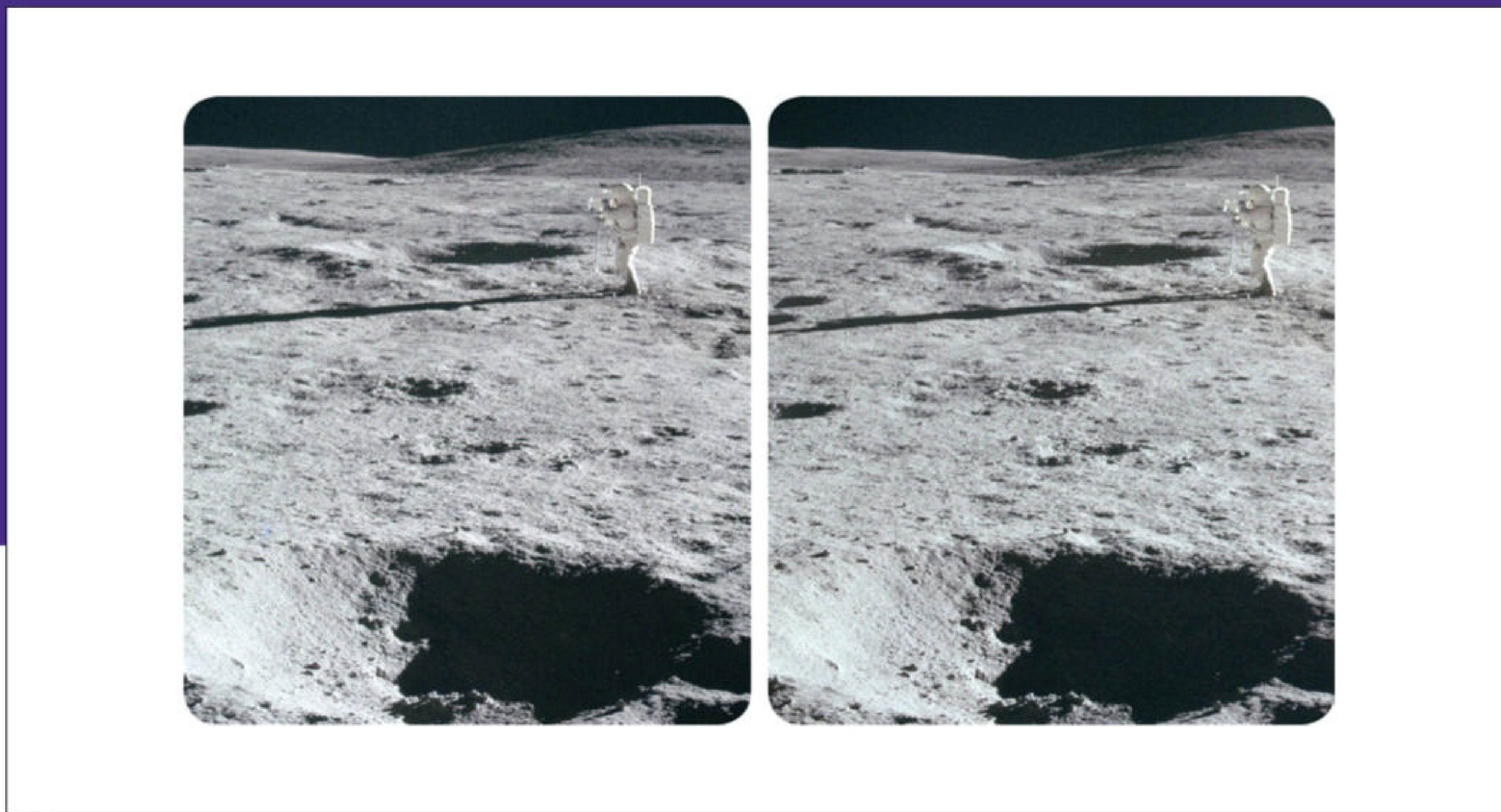
Soon after beginning the descent within *Antares*, the astronauts encountered a problem. The lander's computer signaled an "abort" alert, which they determined was a false alarm due to a faulty switch. But if the alarm were to recur after the descent engine began firing, the computer would treat the false alarm as if it were real and abort the descent. This would cause the craft's ascent stage to ignite and separate from the descent stage, and the LM would return to a lunar orbit.

Back at Mission Control, the flight team enlisted engineers at NASA and at MIT to work on the problem. After a short time, engineers suggested reprogramming the computer onboard *Antares* to ignore the abort signal. Mitchell frantically entered the changes into the computer. It worked, allowing the descent to begin. "It's a beautiful day to land at Fra Mauro," said Shepard in response to the fix.

## HOW TO VIEW OUR 3D IMAGES

There are two ways to view the images printed in 3D. To free view the images with no mechanical assistance, let your eyes relax as you view the photos as though focusing on a point behind them. At first you will see the two images split into four; as your eyes focus at the correct distance, the middle two images will combine to create a single, crisp 3D image. The outer two images will remain on either side of the 3D image and become blurry.

Alternatively, you can use a 3D viewer, such as the Lite OWL viewer designed by Brian May and included with the *Mission Moon 3-D* book, to view images in 3D. Only 5 by 2.5 inches (134 by 64 millimeters) and 0.1 inch (3 mm) thick, the Lite OWL viewer is designed for easily viewing 3D images in books, magazines, modern and vintage stereocards, and even video or other VR content on your smartphone. You can purchase individual Lite OWL viewers separately at **www.MyScienceShop.com**



Shepard shot this image of Mitchell, who casts a long shadow as he operates a TV camera on the cratered soil of Fra Mauro. Astronauts have reported that shadows on the Moon can look quite alien; they are extremely dark due to the absence of an atmosphere to scatter light. NASA/JSC

But another problem cropped up. The landing radar employed by *Antares* failed to recognize the lunar surface, so that altitude and vertical speed data would not show in the LM. The fix this time seemed to be cycling through the craft's radar breakers. At an altitude of about 18,000 feet (5,490 meters), the data readouts came back on, allowing the astronauts to safely pursue the landing. The spacecraft pitched over and Shepard and Mitchell began to see landmarks on the Moon. "There it is," said Shepard upon spotting Fra Mauro as he manually landed the LM. "It's really a wild-looking place here," said Mitchell. The craft ultimately came to a halt just where they had planned. In fact, Shepard's landing came closer to the chosen point than any of the other five lunar landings.

## Lunar activities

On Feb. 5, Shepard and Mitchell made their first of two moonwalks, which would last between four and a half and five hours each. They named the lunar base at their landing position Fra Mauro Base, which was subsequently added to lunar maps showing the Fra Mauro region. As he descended the LM ladder and finally touched the lunar surface with his heavy boot, Shepard said, "And it's been a long way, but we're here." This was the third "first step" of a lunar explorer on a new mission — the first two steps those of Neil Armstrong and Pete Conrad.

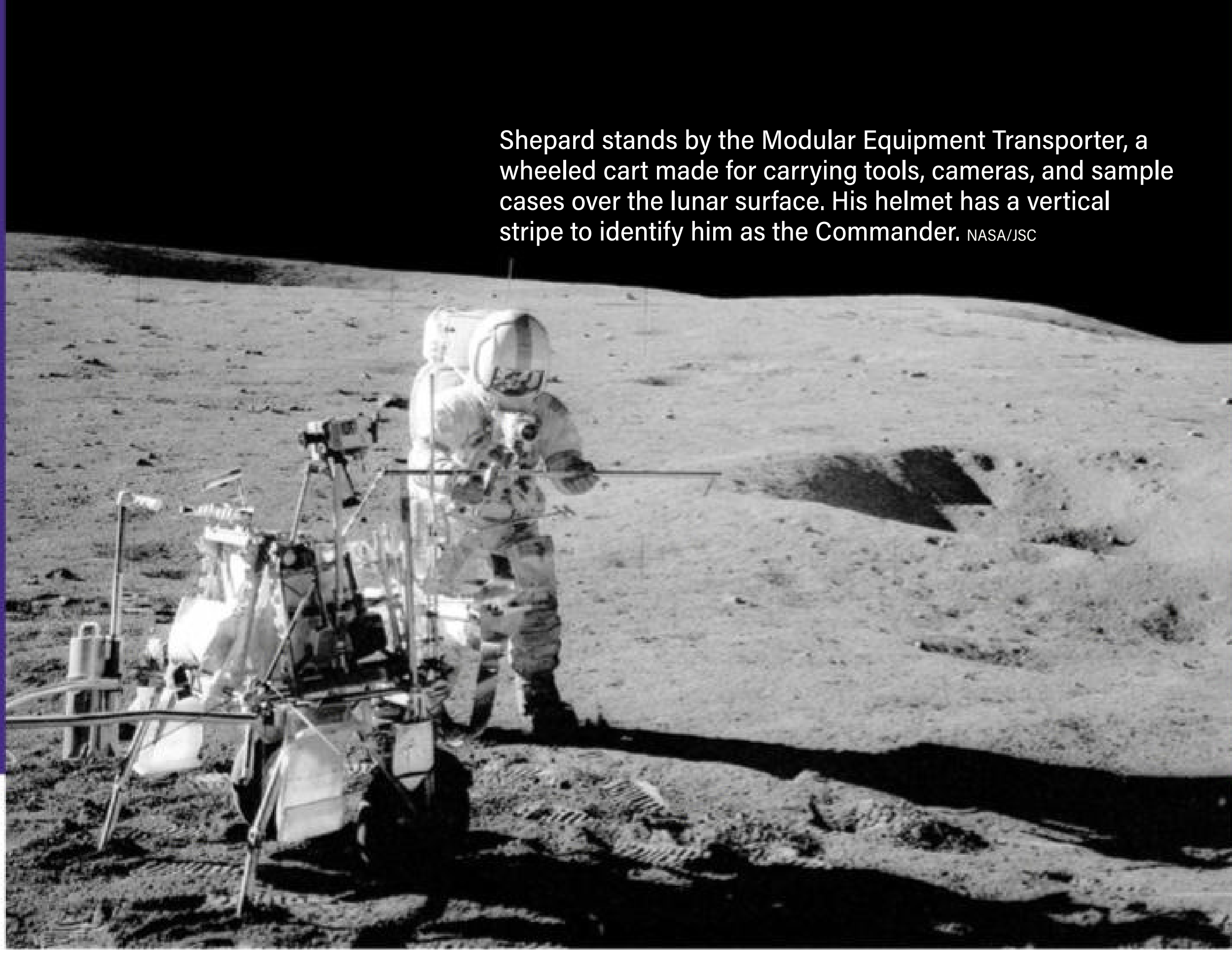
Unlike Apollo 12, this time, the astronauts successfully employed their color television camera, which they planted on the surface at Fra Mauro Base, along with the customary U.S. flag. There would now be broadcasts in natural color showing the astronauts during their moonwalks and activities. NASA had not been satisfied with the appearance the previous missions' pictures, in which it was difficult to differentiate between astronauts. So this time, Shepard wore an Apollo suit that had red stripes on the arms and legs, enabling easy identification of the commander. NASA continued this practice with the remaining Apollo flights and into the era of the space shuttle.

As with the previous missions on the lunar surface, the astronauts deployed the Apollo Lunar Surface Experiments Package, or ALSEP, which contained experiments that would record data on seismology, magnetism, the solar wind, heat flow, and the abundance of ions. They also deployed the Modular Equipment Transporter, a pull cart for transporting equipment and Moon rocks. The astronauts nicknamed the cart the "lunar rickshaw."

The first moonwalk lasted nearly four hours and 48 minutes. It succeeded in all the astronauts hoped to accomplish. Some 13 hours after the first walk ended, the astronauts commenced their second extravehicular activity. Shepard again set foot onto the lunar surface first, followed by Mitchell some seven minutes later. During the second walk, the astronauts planned to walk to Cone Crater, a 1,000-foot-wide (300 m) depression in Fra Mauro.

As the grade angled slightly uphill, Mitchell noted that the walk was a little more exerting. "We're starting uphill now," he said. "It's definitely uphill." Shepard and Mitchell stopped short of the crater by about 100 feet (30 m) and collected a substantial amount of lunar rock and soil samples. Mission planners believed these would be of particular interest geologically because they had been blasted up from deep below the surface.

As the pair continued walking, Shepard noticed how dusty the lunar surface was — how dust was getting kicked up and adhered to the spacesuits. "Nothing like being up to your arms in lunar dust," he said.



Shepard stands by the Modular Equipment Transporter, a wheeled cart made for carrying tools, cameras, and sample cases over the lunar surface. His helmet has a vertical stripe to identify him as the Commander. NASA/JSC

On Feb. 9, 1971, the Apollo 14 crew splashed down in the South Pacific and were recovered by U.S. Navy personnel dispatched from the USS *New Orleans*. In this image, Mitchell steps out of the spacecraft as Shepard and Roosa follow. NASA

The second moonwalk lasted nearly four hours and 35 minutes. Near its end, Shepard made a surprise announcement. He stepped toward the color TV camera and pulled out a makeshift golf club. "Houston, you might recognize what I have in my hand as the handle for the contingency sample return," he blurted. "It just so happens to have a genuine six iron on the bottom of it. In my left hand, I have a little white pellet that's familiar to millions of Americans."

Shepard plopped a golf ball onto the lunar surface. He was an avid golfer and had planned this surprise as a test of his own abilities on the Moon's surface as well as a test of the weaker lunar gravity relative to Earth. "Unfortunately, the suit is so stiff, I can't do this with two hands," he said. "But I'm going to try a little sand trap shot here."

The Apollo 14 commander took a swing, knocking some lunar dust skyward. "Hey, you got more dirt than ball," said Mitchell. Watching from back on Earth, Fred Haise — recovered from his infection during Apollo 13 and acting as a CapCom (capsule communicator) on the ground — said, "That looked like a slice to me, Al."

"Here we go again," said Shepard as he swung again. "Straight as a dime. Miles and miles and miles." Shepard later concluded that the golf ball traveled between 200 and 400 yards (180 and 370 m). Not to be outdone, Mitchell thrust a lunar scoop handle in the air as if it were a javelin, in what could perhaps be called a Micro Lunar Olympics.

They concluded the second moonwalk after collecting some 94 pounds (43 kilograms) of Moon rocks. After 33.5 hours total on the lunar surface and nine and a half hours walking around, the pair prepared to blast off and return to *Kitty Hawk*, with Roosa still orbiting overhead.

*Kitty Hawk* splashed down in the Pacific Ocean south of American Samoa, and the astronauts recovered well from the ordeal. In the wake of the scare over Apollo 13, the Apollo program was solidly back on the right track, and the samples collected and science that had been conducted would help the Moon program enormously.

## Two space programs

The Soviet Union's ongoing space program now essentially consisted of watching the Americans run away with the lunar prize. The Soyuz program continued, but these flights were Earth orbital missions. Through 1970, eight Soyuz missions had taken place, some with rendezvous objectives and others paving the way for coordination with the planned Salyut 1 space station — the world's first space station, to be deployed by the spring of 1971. The launch of this very significant first was planned to mark the 10th anniversary of Yuri Gagarin's flight, but in the end had to be delayed by several days.

The first mission to Salyut 1 was Soyuz 10, launched April 22, 1971. The crew — Vladimir Shatalov, Aleksei Yeliseyev, and Nikolai Rukavishnikov — hoped to rendezvous with Salyut 1 and board the space station, becoming the first station crew in space exploration history. But the docking with Salyut 1 was unsuccessful and the crew had to return to Earth.

Several months later, another crew set off for Salyut 1. Soyuz 11, with cosmonauts Georgy Dobrovolsky, Vladislav Volkov, and Viktor Patsayev, blasted off from Baikonur, Kazakhstan, on June 6 and docked with Salyut 1 one day later. The cosmonauts remained on board the space station for 22 days, setting an endurance record in space that would stand for another two years.

When they entered the station, the crew discovered a smoky smelling atmosphere. On the 11th day in the station, a small fire broke out. The cosmonauts had hoped to observe a rocket launch from the station, but it was delayed. Nonetheless, they made a TV broadcast back to Earth and generally enjoyed the stay.

Tragically, when the capsule was recovered on Earth after landing June 30, the mission recovery team opened it to find all three crewmembers dead. The cosmonauts had bluish patches on their faces and had hemorrhaged from their mouths and noses. The official cause of death was given as asphyxiation. The original commander of the mission, Alexei Leonov, had advised the crew from the ground to close valves between the orbital and descent modules manually, because he did not trust the automatic mechanism. The cosmonauts did not follow his suggestion, however, and this may have been the cause of the fatal event.

Shepard made this image of an astronaut boot print using the Apollo Lunar Surface Closeup Camera during the second Apollo 14 moonwalk. Thanks to its slightly cohesive properties, the lunar soil retains the shape of the print, including the nearly vertical sides of the treads. The lunar soil's "stickiness" results from many factors, including particle size and electrostatic charge. NASA/JSC

The Soviets did carry on with the Lunokhod program, a meticulously planned series of missions to place robotic rovers on the Moon. Russian for "moonwalker," Lunokhod was intended to provide backup and support for later Soviet crewed missions to the Moon. After years of testing in secret, the first Lunokhod (designated 201 or 0) launched in 1969, but shortly after launch, the rocket disintegrated. As a follow-up, Soviet engineers designed Lunokhod 1, which launched Nov. 10, 1970. Nearly 8 feet (2.4 m) long, the rover was similar in appearance to later Mars rovers that have explored the planet. Its eight skeleton design wheels ferried it around, and it carried a suite of instruments, including antennas, television cameras, soil-testing devices, spectrometers, an X-ray telescope, and a cosmic ray detector. Lunokhod 1 successfully landed on the Moon in Mare Imbrium on November 17 and operated its experiments until September 1971. A second, more complex Lunokhod was developed and launched to the Moon in 1973.

Although the Soviet program would not land cosmonauts on the Moon, it made important contributions to lunar science. And underneath the veil of the space race, something else was happening. Alongside the direct competition, Soviet and American space explorers were forming a partnership that would become stronger and stronger as the months and years passed, even as the U.S. planned its next Moon mission: Apollo 15.

---

*Astronomy editor* **David J. Eicher** *is the author of 25 books on science and history.* **Brian May** *is an astronomer and founding member and guitarist of the legendary rock band Queen.*

*This story is adapted from* Mission Moon 3-D: A New Perspective on the Space Race, *by David J. Eicher and Brian May, foreword by Charlie Duke, afterword by Jim Lovell, © 2018 by London Stereoscopic Co. and MIT Press, Boston.*

## EXPLORE FROM HOME

*Mission Moon 3-D: A New Perspective on the Space Race,* by David J. Eicher and Brian May (with foreword by Charlie Duke and afterword by Jim Lovell), presents the story of the historic lunar landings and the events that led up to them, told through text and three-dimensional images.

*Mission Moon 3-D* contains new and unique stereoscopic images of the Apollo Moon landings to show what it was like to walk on the lunar surface. The triumph of the Apollo 11 Moon landing takes center stage, with detailed stories and visually stunning images from the lunar missions that followed. The book includes 150 stereo photos of the Apollo mission and space race — the largest group ever published — and presents photos never seen before in stereo.

The book delivers a comprehensive tale of the space race. New stories appear from the astronauts, including Jim Lovell's anecdotes about the perilous return of Apollo 13.

*Mission Moon 3-D* also includes a history of the music and special movements of the 1960s and beyond that transformed the world, from Vietnam and Woodstock to Live Aid. Don't miss out on this unique treasure.

When the Moon reaches totality during a lunar eclipse, it often takes on a reddish hue. That's why many refer to such an eclipse as a Blood Moon.

# The MOON turns RED

## Our only natural satellite submerges itself in Earth's shadow this month.

BY MICHAEL E. BAKICH

Total eclipses of the Moon are fun. During one of these events, the entire Moon passes through Earth's umbra, the innermost and darkest part of its shadow.

A total lunar eclipse generally lasts for hours, requires no equipment to see, and is completely safe to look at — no filter required. There's no blinding Sun in the sky; all we're watching is Earth's shadow fall across Luna's face. And on the morning of Wednesday, May 26, many observers on our planet's night side will see that happen.

The most recent total lunar eclipse occurred Jan. 21, 2019. The last one visible in the continental U.S. happened July 27, 2018. Since then, amateur astronomers have been counting the days for the Sun, Earth, and the Moon (in that order) to line up once again.

The only "bad" news is that totality during this eclipse is brief. It lasts a scant 14 minutes 31 seconds. Although that's short for *lunar* totality, it's almost twice as long as the longest *solar* eclipse totality possible. So, make plans now to view this event. There's lots of cool stuff to see.

### Where and when?

The entire eclipse will be visible throughout Australia, New Zealand, Southeast Asia, Chile, Argentina, and western North America. In the U.S., those who position themselves as far west as possible will have the best views.

The eclipse begins at 4:47:39 A.M. (all times are Eastern Daylight Time), when the Moon enters Earth's penumbra — its lighter, outer shadow. Our satellite enters the umbra at 5:44:59 A.M., signaling the start of the first partial phase of the eclipse. Totality begins at 7:11:27 A.M. and lasts until 7:25:58 A.M. From there, the event plays itself out in reverse, with the

partial phase ending at 8:52:26 A.M. Finally, more than five hours after the Moon first entered Earth's outer shadow, it fully exits the penumbra at 9:49:47 A.M., officially ending the eclipse.

Totality is so brief during the May 26 eclipse because the Moon doesn't pass through the center of our planet's umbra. Instead, Luna's northern edge passes just inside the umbra's northern limit. In contrast, its southern edge lies a lot closer to the shadow's center, so the Moon's southern half will look much darker than its northern half. Because the Moon crosses a large range of the shadow's depths throughout totality, the appearance of its face will change significantly as the eclipse progresses.

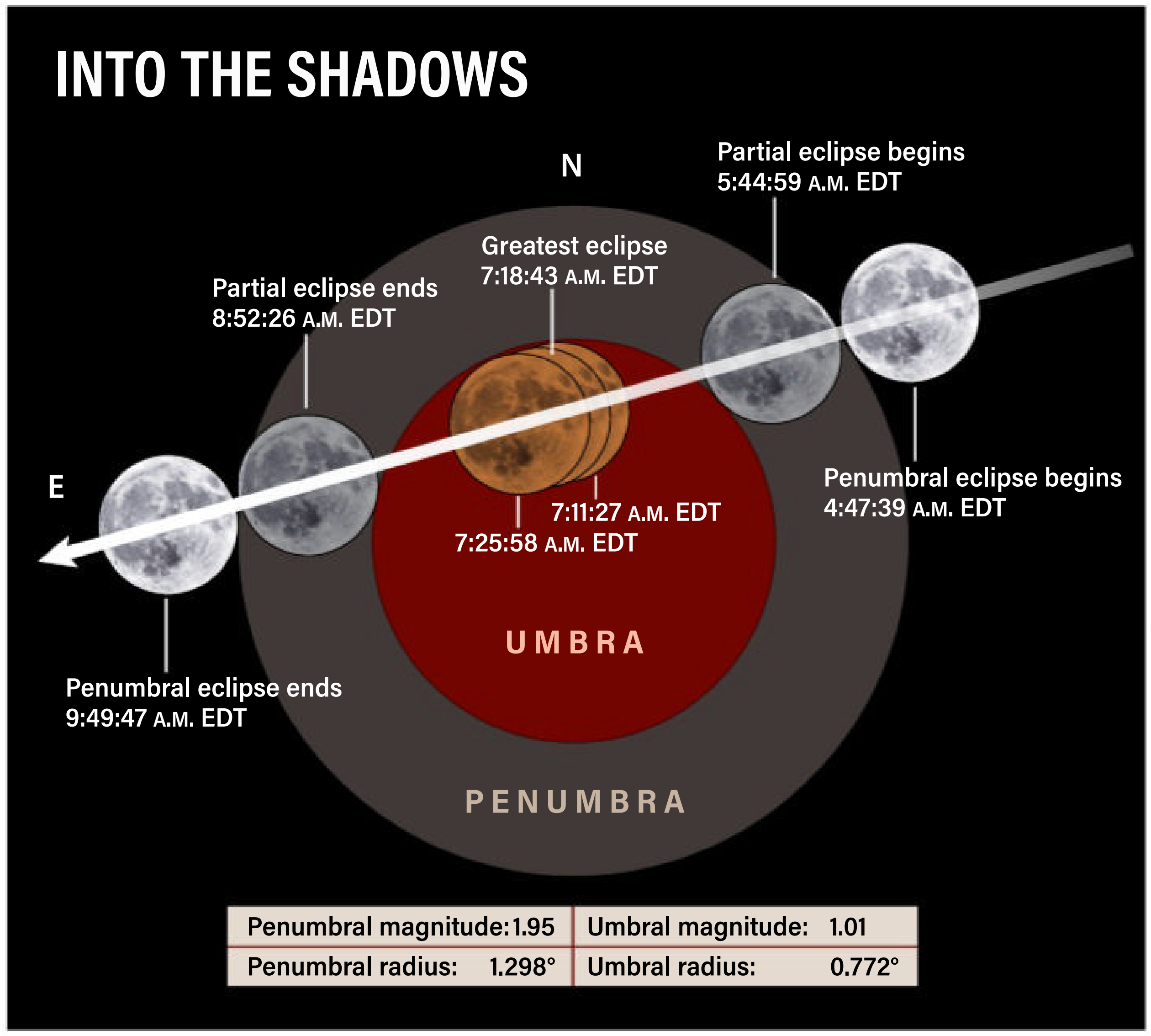



ILLUSTRATION: *ASTRONOMY*: ROEN KELLY AFTER F. ESPENAK (NASA/GSFC); BOTTOM OF PAGE: JAMIE COOPER

## How dark will it get?

The Moon looks different during the total phase of each eclipse because it takes different paths through Earth's umbra. The more centered it is, the darker it will get. During this eclipse, therefore, the Moon will definitely look brighter than it would if it passed through the central part of Earth's shadow. But Luna's appearance also depends on our atmosphere, which contains water droplets and solid particles like dust and ash, reducing the air's transparency.

In addition to darkening, the Moon takes on color during totality as Earth's atmosphere diverts some sunlight into the shadow. The atmosphere also scatters shorter (bluer) wavelengths out of that light, both reddening and darkening the Moon's face. Lots of clouds along the limb of our planet, as seen from the Moon, can make Luna appear even darker still.

One fun activity is to try to estimate the darkness of a total lunar eclipse. Most observers use a five-point scale developed in 1921 by French astronomer André-Louis Danjon. You can use your naked eyes, binoculars, or a telescope, as long as you make your estimate near the middle of totality.

In Danjon's system, L values stand for luminosity, or how bright the Moon looks during totality. If L=0, the Moon is almost invisible. When L=1, lunar details will be difficult to distinguish. For L=2, the Moon is deep red or rust colored. L=3 indicates a brick-red Moon, while Earth's umbral shadow projected on the Moon may have a bright or yellow rim. And if L=4, the Moon looks bright copper-red or orange and the shadow may have a bluish rim.

## All 'round the Moon

During this totality, the Northern Hemisphere's summer constellations will surround the Moon. Throughout the eclipse, the Moon will be in the northern part of Scorpius the Scorpion. That pattern's brightest star, 1st-magnitude Antares (Alpha [α] Scorpii), will lie 6.5° southeast of the Moon. Antares' red color will complement the orange Moon, especially through binoculars. (Note: 7×50 binoculars have a 7° field of view.)

No other bright stars are close to the Moon during the eclipse. Spica (Alpha Virginis) stands 41° to its west and Altair (Alpha Aquilae) lies 62° to the northeast. Saturn, at magnitude 0.5, will stand some 70° away in Capricornus, and Jupiter, blazing at magnitude –2.4, will be about 18° farther east in Aquarius.

MOON COLLAGE: GOWRISHANKAR

## "Totally" safe

The public is used to hearing the words *eclipse* and *warning* together. While that's valid for solar eclipses, a lunar eclipse poses no danger to your eyes. So, you won't need a filter and you can magnify the sight with binoculars or a scope.

Because this event occurs early on a Wednesday, people with work or school obligations may choose not to seek it out. The prospects of an eclipse viewing party, therefore, are slim. But consider waking your family 10 minutes before totality starts. Within half an hour, they'll be back in bed and you'll have exposed them to some cool, easy-to-understand science. Many astronomy clubs and science centers also plan to host events.

Observing a total lunar eclipse isn't hard science. It takes little effort and offers a big payback. How long you watch is up to you. You can use optics or not. And you can observe it from the darkest site on Earth or the heart of a city. But however you view this eclipse, have fun!

---

**Michael E. Bakich** *is a former senior editor at* Astronomy *magazine and rarely misses an opportunity to view a total lunar eclipse.*

# Explore the EXTREME SOUTHERN SKY

Don't miss out on these Southern Hemisphere clusters, nebulae, and galaxies. BY MICHAEL E. BAKICH

**A POPULAR OLD SAYING CLAIMS,** "Absence makes the heart grow fonder." For me, this describes my love of the southern sky. I've spent maybe 50 nights total under it, but each one has been filled with discovery and fascination.

For this story, I've chosen deep-sky objects in the far south — within 30° of the South Celestial Pole. Once you point a telescope toward that region, you'll encounter constellations you may

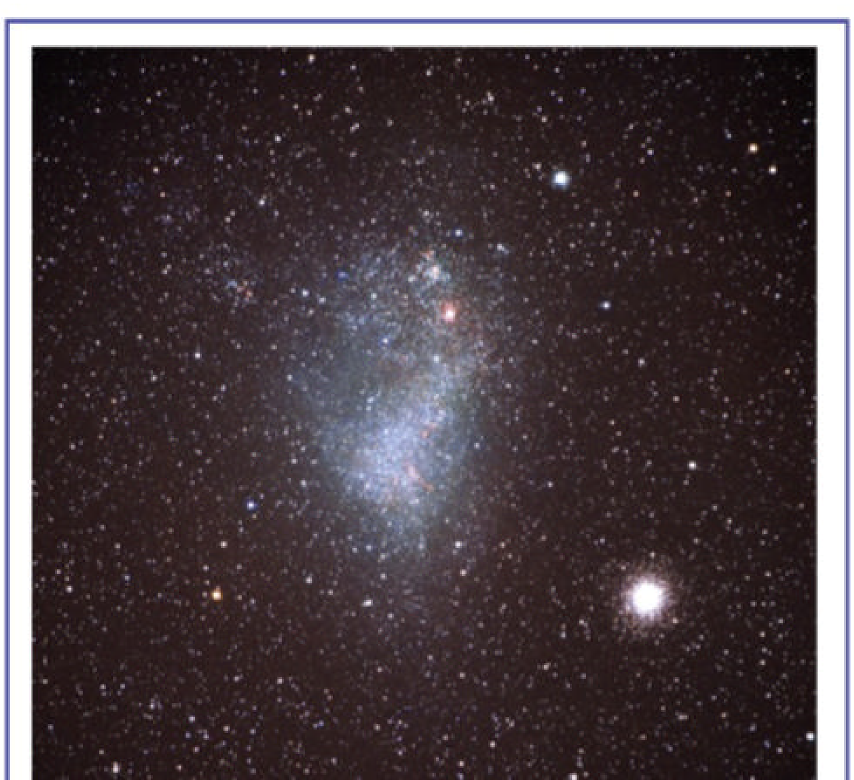
The southern Milky Way arcs across the sky at the Paranal Observatory in Chile. The Large and Small Magellanic Clouds are visible below the band of our galaxy. ESO/Y. BELETSKY

not be familiar with: Apus, Ara, Carina, Centaurus, Circinus, Crux, Dorado, Horologium, Hydrus, Indus, Mensa, Musca, Octans, Pictor, Reticulum, Triangulum Australe, Tucana, and Volans. And although Carina, Centaurus, and Crux contain bright stars you can navigate by, luminaries in the other groups are few and far between.

What are the best locations to view these southern wonders? One is the tip of South America, either in Chile or Argentina. From a latitude of 50° south, the South Celestial Pole stands 50° high, so the objects in this story will never set. Instead, they'll lie between 20° and 80° above the horizon all night.

But let's say you're heading to Melbourne, Australia. From there, targets on this list will appear about 12° lower. Your best views from either location will come when an object stands highest above the horizon.

I've listed these objects in order of right ascension. Pick one that's high in the sky, and the subsequent objects will rise to their highest points after it. Good luck!



The Small Magellanic Cloud (center) and the globular cluster 47 Tucanae (lower right) make a magnificent naked-eye pairing. The globular cluster NGC 362 is also visible in this image, above and to the right of the Small Magellanic Cloud. AKIRA FUJII

## The list

As it happens, our first target is one of the best: **47 Tucanae** (NGC 104). This globular cluster forms a celestial pairing in Tucana with the Small Magellanic Cloud — both objects are easily visible to the naked eye. Among globulars, only Omega Centauri (NGC 5139) outshines NGC 104.

To the naked eye, 47 Tucanae

appears as a magnitude 3.8 fuzzy "star." A 3-inch telescope will begin to resolve this cluster's stars, but they really put on a show when you use an 8-inch or larger scope. Through such instruments, the cluster is a 50'-wide ball of stars you can resolve nearly to the core. Be sure to note the many streams of stars that emanate from its central region 6' in diameter.

Our second target, bright globular cluster **NGC 362**, lies in Tucana on the northern edge of the Small Magellanic Cloud. It's not part of that galaxy, however, and sits seven times closer to us.

Sharp-eyed observers will see it without optical aid as a magnitude 6.5, extended "star." Its apparent diameter is 12.9', more than 40 percent that of the Full Moon. Through an 8-inch telescope, NGC 362 explodes with detail. Well, except for the core — you'll need a larger scope and high magnification to resolve any of the stars near the cluster's center.

Our next object is a true southern showpiece. **NGC 1313** sits in the southwest corner of Reticulum, 3.2° southwest of magnitude 3.8 Beta (β) Reticuli. This spiral galaxy glows at magnitude 8.9 and measures 11.0' by 7.6'.

Through an 8-inch scope, the first feature you'll notice is the thick bar with a slight central bulge that orients north-south. Spiral arms extend eastward and westward. The eastern bar has two sections divided by a dark region. The knots you see are star-forming regions along the bar and arms.

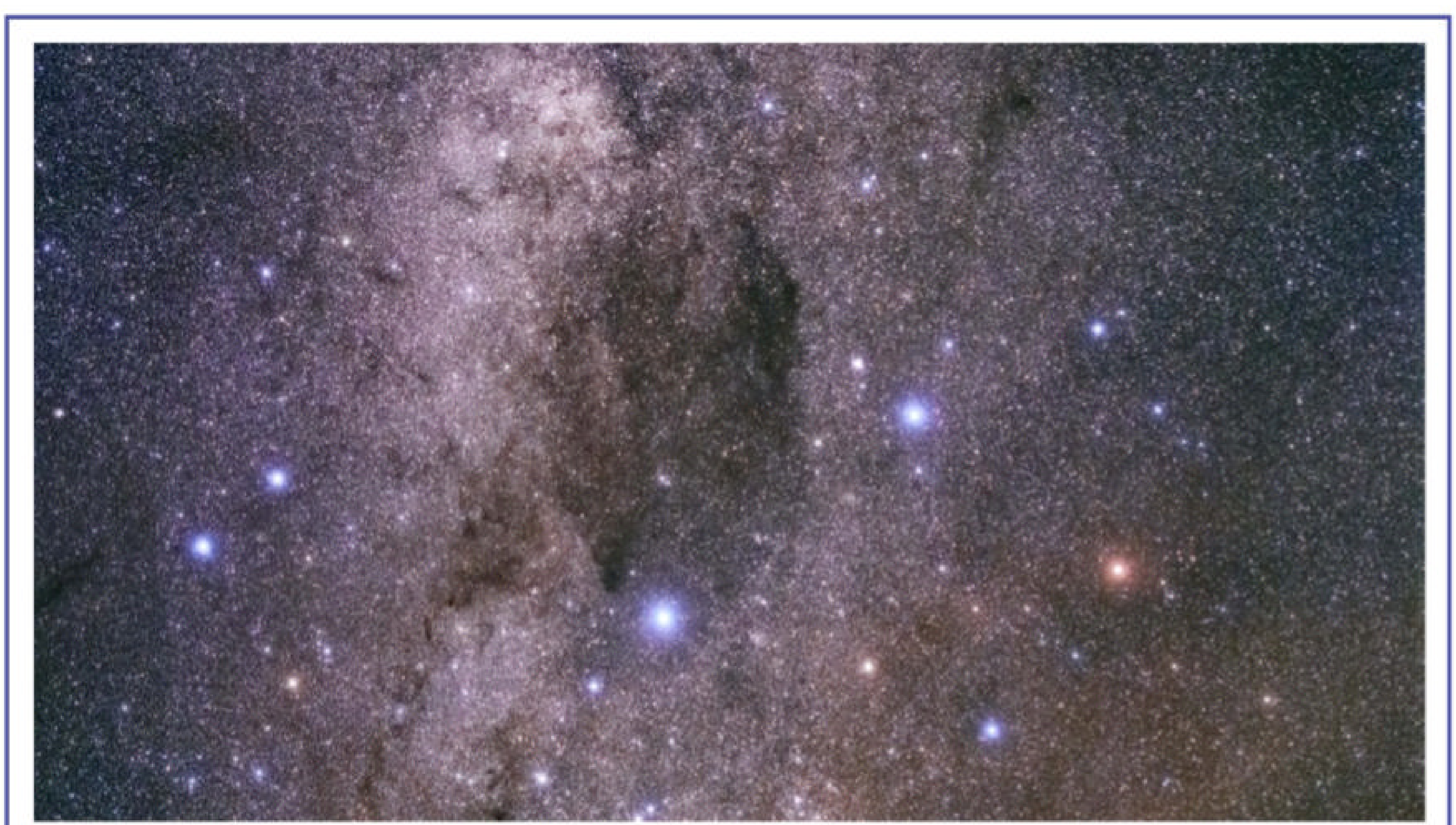
Most northern observers unfortunately haven't experienced our next target: the **Tarantula Nebula**. This huge (30' by 20') emission nebula lies in the Large Magellanic Cloud, in Dorado.

Even through a 4-inch scope, the Tarantula shows loops and filaments. A dense central bar runs north to south. Open star cluster R136 is easy to spot as a 1'-wide region of several dozen bright stars. The longest filament begins near the cluster's center and extends 7' to the south. It then extends eastward and loops an equal distance to the north.

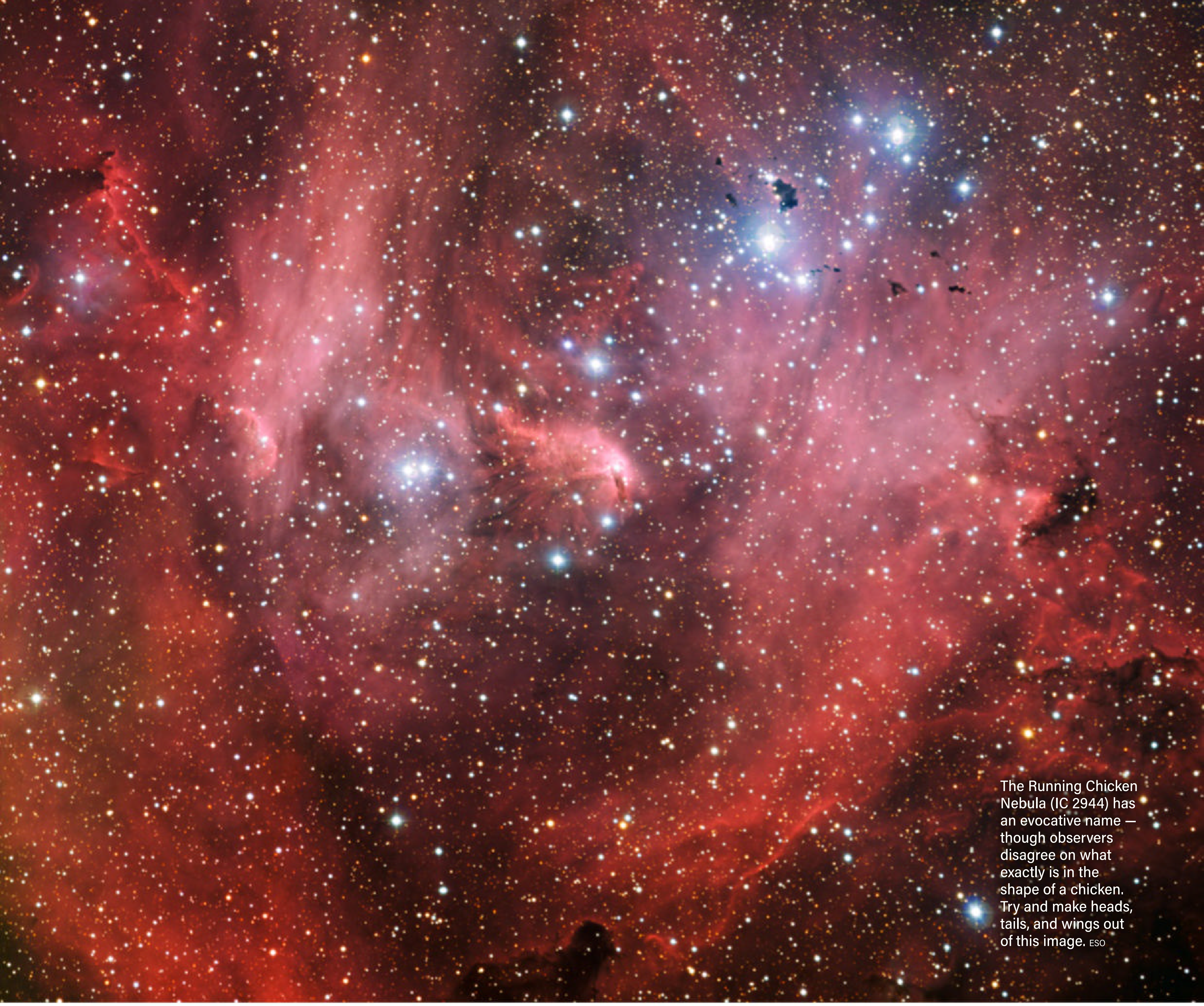
Our next treat carries an unusual name. The **Meathook Galaxy** (NGC 2442) lies 2.3° southeast of magnitude 4.0 Delta (δ) Volantis. Through a 10-inch scope, this magnitude 10.4 barred spiral shows symmetrical hooks curving from a faint, thick, 4'-long bar and a bright core. Its distorted form, which measures 5.4' by 2.6', hints at past interaction with other galaxies.

After the Meathook, head into Carina, 3.3° west-southwest of magnitude 1.9 Avior (Epsilon [ε] Carinae) for **NGC 2516**. You'll have no trouble spotting this magnitude 3.8 object with your naked

The Jewel Box (NGC 4755) is filled with stellar gems ranging in color from pale blue to ruby red. ESO



The Coalsack Nebula is an interstellar dust cloud that blots out a section of the Milky Way. Easily visible to the naked eye, it carries deep spiritual meaning in Australian Aboriginal astronomy as the head of the Emu in the Sky, a constellation composed of dark nebulae. CHIRAG UPRETI



The Running Chicken Nebula (IC 2944) has an evocative name — though observers disagree on what exactly is in the shape of a chicken. Try and make heads, tails, and wings out of this image. ESO

eyes — it's one of the sky's 10 brightest open clusters. It also spans a whopping 30'.

Through a 6-inch scope, you might count as many as 75 stars. Here, the stars divide into two brightness ranges. The upper class ranges from magnitude 5.8, the cluster's brightest star, through magnitude 8. Unless you use a magnification above 250x, all those bright stars will mask the many faint stars this cluster contains.

Still in Carina, get ready for a glorious view. Open cluster **NGC 3114** lies in a spectacular star field 5.8° east-southeast of magnitude 2.2 Aspidiske (Iota [ι] Carinae). It glows at magnitude 4.2 and spans 35'.

Through a 4-inch telescope, you'll first spot two bright stars in the cluster's area, glowing at magnitudes 6.2 and 7.3. Have fun making patterns with the several dozen stars that surround this pair.

Our next object, **NGC 3195**, is a faint (magnitude 11.6) but high-surface-brightness planetary nebula 1.5° west-southwest of magnitude 4.5 Delta$^2$ ($\delta^2$) Chamaeleontis. A 4-inch telescope at 100x will reveal this object as a slightly fat "star" 38" in diameter. Through a 10-inch scope, crank the power beyond 200x, and you'll have no problem seeing the nebula's extended nature. At this magnification, it appears slightly stretched in a north-northeast to south-southwest orientation.

Next up is the dazzling **Theta Carinae Cluster** (IC 2602), which surrounds the star of the same name. It shines at magnitude 1.9 and spans 50'. Observers also call it the Southern Pleiades.

Binoculars will give the best view because anything above the lowest power in a telescope will magnify the area too much, really spreading the stars out. That said, if you own a short-focal-length refractor and an eyepiece that will provide at least a 1.5° field of view, you're in for a wonderful experience.

At low power, the Southern Pleiades appears like two clusters separated by a 0.3° gulf. In the western part, you'll see Theta (θ) Carinae and a pair of stellar

## SOUTHERN DOUBLES

If you've had your fill of clusters, nebulae, and galaxies, try spying these fine double stars. The widest, Gamma (γ) Volantis, will be resolved in just about any telescope and even large binoculars. The closest pair, Beta (β) Muscae, will be nicely resolved in a 6-inch scope.

| Star | R.A. | Dec. | Magnitudes | Separation | Colors |
|---|---|---|---|---|---|
| Kappa (κ) Tucanae | 1h16m | 68°53' | 5.1/7.3 | 5.4" | White/Yellow |
| Theta (θ) Reticuli | 4h18m | 63°15' | 6.2/8.2 | 2.9" | Blue/White |
| Gamma (γ) Volantis | 7h09m | 70°30' | 3.8/5.7 | 13.6" | Yellow/White |
| Upsilon (υ) Carinae | 9h47m | 65°04' | 3.1/6.1 | 5" | White/White |
| Alpha (α) Crucis | 12h27m | 63°06' | 1.4/1.9 | 4" | Blue/Blue |
| Beta (β) Muscae | 12h46m | 68°06' | 3.7/4.0 | 1.3" | Blue/Blue-white |

Despite appearances, the Spiral Planetary Nebula (NGC 5189) is not a galaxy — rather, it is the result of an aging star becoming a white dwarf and puffing off its outer layers into space. NASA, ESA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

arcs that originate at that star. One curves northward and the other southward. The eastern half of IC 2602 looks to me like a miniature version of the main part of the constellation Orion, albeit with stars of different brightnesses.

You'll find our next target, the **Pearl Cluster** (NGC 3766), 1.5° north of Lambda (λ) Centauri — and what a sight it is. At magnitude 5.3, you can see this cluster without optical aid, but you'll have to work at it because of the rich star field it's in. Use 15x binoculars, and you'll see several dozen stars. But the finest view comes through a telescope that magnifies between 75x and 100x.

Through a 4-inch scope, you can count 100 stars within a 12'-wide circle, the brightest of which shines at 7th magnitude. That collection in itself provides a sweet view, but there's more. Riding seemingly in front of a pure-white carpet of diamonds are two pale rubies. One lies midway between the cluster's center and its eastern edge. The other lies the same distance from the center toward the west.

For our next target, go back to 3.1-magnitude Lambda Centauri. Beginning with that star and running toward the southeast is the huge (65' by 40') open star cluster **Collinder 249**. Its oval shape spans 1°. But this area contains a lot more than a star cluster. The **Running Chicken Nebula** (IC 2944), a large glowing cloud of hydrogen, surrounds Lambda. You'll spot it through a 4-inch scope.

The first dark nebula on our list, the **Coalsack**, has the greatest impact as a naked-eye object. The Coalsack is huge, measuring 400' by 300'. Optics shrink the field of view, meaning you don't get much of the bright Milky Way starfield for comparison with the Coalsack. Binoculars and telescopes also show stars within the Coalsack, lessening its appeal.

I consider the next target, the **Jewel Box** (NGC 4755), also known as the Kappa Crucis Cluster, the sky's finest open cluster. It's not the biggest (10') or the brightest (magnitude 4.2), or even the most populous. The reason NGC 4755 stops me in my tracks is its colorful stars.

Almost all open clusters contain hot, recently formed stars, which appear blue or white through a telescope. But in the Jewel Box, you'll spot stars glowing blue, yellow, and orange.

A 6-inch telescope and an eyepiece that yields 50x may be the best combination with which to view NGC 4755. Through this setup, you'll see nearly a dozen stars that exhibit color, plus 20 additional white stars and a faint backdrop composed of some 200 cluster members.

Next, head to Musca for **NGC 4833**, which lies 0.7° north-northwest of magnitude 3.6 Delta Muscae. This magnitude 7.8 globular cluster is easy to spot through binoculars or a finder scope, but it's about as loosely concentrated as these objects get. You'll see about 30 of its outer stars randomly strewn across the 13.5'-wide field of view through an 8-inch telescope at 200x. More stars lie in the central area, which stretches east to west.

The Tarantula Nebula is a sprawling volume of ionized hydrogen breeding an impressive amount of stars. If it were within our galaxy — and not the Large Magellanic Cloud — at the same distance as the Orion Nebula, its brilliance in the night sky would cast visible shadows. KFIR SIMON

The Meathook Galaxy (NGC 2442) gets its name from its distinctly curved spiral arms, which were likely warped by a near-collision with another galaxy. ESO

*Almost all open clusters* contain hot, recently formed stars, which appear blue or white through a telescope.

Also in Musca you'll find the **Spiral Planetary Nebula** (NGC 5189), 2.7° east-southeast of magnitude 5.7 Theta Muscae. It glows at magnitude 9.9 and measures 153" across. Take a close look at this object. Do you think it looks like a barred spiral galaxy? A thin, bright bar traverses the planetary nebula and surrounds its 13th-magnitude central star. Through a 12-inch telescope at 300x, you'll see a nebulous arm wrapping to the north from the west end of the bar and curling around an 11th-magnitude star.

Then, it's off to Centaurus for **NGC 5281**. It's a bright (magnitude 5.9) open cluster 3.3° southwest of Hadar (Beta Centauri). A 4-inch telescope at 100x reveals three dozen stars in a 5'-wide area. The cluster's brightest member glows at magnitude 6.6 and lies just north of center. From that star, a curve of six fainter ones arcs southwestward.

Our next object, open cluster **NGC 6025**, lies at the northern edge of Triangulum Australe, right at that constellation's border with Norma. You can find it 3.1° north-northeast of Beta Trianguli Australis. If you're at a dark site, try spotting magnitude 5.1 NGC 6025 with your naked eyes. Through a 6-inch telescope, you'll count roughly 40 stars between magnitudes 7 and 11 within a circle 12' in diameter.

If you're ready for something other than an open cluster, head to southern Ara, 1.2° northeast of magnitude 4.7 Zeta (ζ) Apodis, to find globular cluster **NGC 6362**. This fine sight glows at magnitude 7.5 and spans 10.7'.

Through a 4-inch telescope at 150x, you'll see a slight central concentration surrounded by a grainy halo composed of unresolved stars. A 12-inch scope at 250x will reveal 25 individual stars. Two magnitude-10 stars sit in the foreground.

You can spot the **Great Peacock** (NGC 6752), one of the sky's brightest globular clusters, with your naked eyes from a dark site. Look for it 3.2° northeast of magnitude 4.2 Lambda Pavonis. This cluster appears big (20.4') and bright (magnitude 5.5) for the reason you'd think — it's close. NGC 6752 lies only 13,000 light-years from Earth.

Through any optics, this is a spectacular sight. A 6-inch scope reveals hundreds of stars orbiting a concentrated core. The brightest glows at magnitude 7.4 and sits just 4' south-southwest of the cluster's center. Many starry chains radiate in various directions from the center, giving NGC 6752 its popular name.

You'll find our final object in Octans, the constellation that surrounds the South Celestial Pole: **Melotte 227**. Though its discoverer, British astronomer Philibert Jacques Melotte, deemed it an open cluster in 1915, we now know it is only a random alignment of stars. To find it, look 4.8° southwest of magnitude 3.7 Nu (ν) Octantis. Melotte 227 glows at magnitude 5.3 and measures a worthy 50' in diameter. Use low power, and you'll spot 15 stars brighter than magnitude 10.

If you have a chance to lay eyes on these objects, make the most of it. While familiar to residents of the global south, for visitors, they are sights to be savored.

**Michael E. Bakich** *is a contributing editor of* Astronomy.

WE TEST

# Celestron's StarSense

## Guided by your smartphone, these scopes are easy to use and on target every time.

BY PHIL HARRINGTON

**CHOOSING A FIRST TELESCOPE** is a difficult task for a fledgling amateur astronomer. Frequently, newcomers pick telescopes with computerized go-to controls, only to discover after a lot of frustration — and expense — that the telescope is too complicated to use right out of the box. Or, they go with a simple telescope that requires finding objects manually using a finder scope. But in today's light-polluted world, that can be a tall order — sometimes just seeing basic constellations is impossible.

Celestron has tackled head-on the challenge of choosing equipment as a beginning observer with their StarSense Explorer telescopes. This entry-level line combines computerized aiming with the familiarity of what you probably have within arms' reach: your smartphone.

### Meet the StarSense Explorers

The line of StarSense Explorer telescopes has four models. In order of increasing aperture, there are two refractors — the 3.1-inch (80 mm) f/11 LT 80AZ and 4-inch (102 mm) f/6.5 DX 102AZ — and two reflectors — the 4.5-inch (114 mm) f/9 LT 114AZ and 5.1-inch (130 mm) f/5 DX 130AZ. The LT models share a common altitude-azimuth mount, with a cellphone cradle attached to the telescope tube. Each DX scope rides on its mount side-saddle, with your smartphone sitting directly across the altitude axis from the telescope.

Some readers may recall that we tested Celestron's StarSense AutoAlign add-on accessory in the July 2014 issue. After it's attached to a Celestron GoTo telescope, the StarSense AutoAlign technology uses a built-in digital camera to take a series of wide-field sky images. Those images are instantly scanned for bright, recognizable stars to calculate the coordinates of the image's center and determine where the telescope is pointed. (This is called plate solving.) It works great. The StarSense Explorer telescopes do the same thing, but instead use your smartphone's GPS and camera aimed at a precisely tilted, factory-set mirror.

To be clear, none of the StarSense Explorer models are motorized go-to telescopes. Instead, they are "push-to." The observer is the motor. After selecting a target with the free Celestron StarSense app, the observer follows the arrows on the phone's screen, manually moving the telescope until the bull's-eye turns green. The target is then ready to view in the eyepiece.

The StarSense app is available for iOS and Android devices but has minimum phone requirements. The iOS version works with the iPhone 6 and newer, while the Android version requires phones manufactured in 2016 or later, running at least Android 7.1.2, with a built-in camera, gyro, and accelerometer. While the dock is flexible enough to hold larger phones like the iPhone 11 Pro Max, it will not secure iPad Minis or similarly sized tablets. You'll find a complete list of compatible devices at http://celestron.com/SSE.

Other scopes in the StarSense Explorer line include another reflector and two refractors. Shown here is the 3.1-inch (80 mm) f/11 LT 80AZ refracting model.

The Celestron StarSense Explorer DX 130AZ is a 5.1-inch (130 mm) f/5 Newtonian reflector ideal for beginning observers. It comes complete with a preassembled mount and tripod, two eyepieces, and several other goodies. ALL IMAGES: CELESTRON

Although StarSense Explorers do not track the sky automatically like go-tos, they are far simpler for beginners to use and enjoy. But are they as accurate for finding targets? To answer that question, I put the DX 130AZ to the test.

### Testing the DX 130AZ

The scope arrived securely packaged in a double-walled box. Inside was the scope itself, a preassembled mount and tripod, and a box of goodies: the smartphone dock, a pair of flexible slow-motion arms, a red-dot finder for aiming the scope by eye alone, an eyepiece/accessory tray, 25mm and 10mm eyepieces, and clearly written instructions.

The telescope tube attached to the mount easily via a dovetail plate that locks it securely into the mating side-mounted base. The spring-loaded smartphone dock locked into the altitude axis' mating bayonet with a discernible click. The dock held my iPhone securely no matter which direction the mount was aimed, from horizon to zenith. That's important

# Explorer


The StarSense Explorer scopes are "push-to" mounts that the user moves under the direction of the Celestron StarSense app running on a smartphone. Snap your phone into the secure dock, complete the on-screen instructions to align it, and you're ready to go.

## PRODUCT INFORMATION

**Celestron StarSense Explorer DX 130AZ**
**Type:** Newtonian reflector
**Aperture:** 5.1 inches (130 millimeters)
**Focal length:** 650mm
**Focal ratio:** f/5
**Focuser:** single-speed rack-and-pinion
**Length:** 25 inches (63.5 centimeters)
**Weight:** 18 pounds (8.2 kilograms) fully assembled
**Price:** $399.95
**Contact:** Celestron
2835 Columbia St.
Torrance, CA 90503
310.328.9560
www.celestron.com

because the phone's aim is critical. The dock's secure locking system prevents it from shifting during use, but the phone's aim toward the dock's tilted mirror needs to be calibrated after initial set-up. The StarSense app offers easy-to-follow instructions to do this quickly by turning the dock's fine-thread adjustment screws.

The on-screen instructions recommend doing the alignment during the day on a distant terrestrial target, but I opted for the Moon instead. First, I attached the red-dot finder to its mounting shoe and then swung the telescope the Moon's way. As luck would have it, the finder and the scope were in alignment from the factory. Continuing through the app's instructions, I zoomed in on the Moon's image on my phone's screen and turned the dock's adjustment screws until the image was centered.

The Moon was nicely displayed in both eyepieces and would surely impress first-time observers. As you grow more seasoned, however, I would recommend new eyepieces. The 130's focuser accepts 2-inch barrels, but high-quality 1.25-inch Plössls would be ideal.

With the scope and phone aligned, I was ready to explore with the Explorer. The app shows the sky, complete with constellation names and line drawings. Along the bottom of the screen are several options. Pressing the pulsating star icon brings up a list of suggested targets, divided into "Tonight's Suggested Objects" and "Tonight's Challenge Objects." Each gives a little capsule summary, including whether it is "City Viewable" or "Dark Sky Viewable." The list is limited to the Messier catalog and other relatively bright deep-sky objects, as well as prominent stars, double and binary star systems, asterisms, and, of course, the Moon and planets. The choices are designed to match realistic expectations for the scope's aperture.

I put aiming accuracy to the test right away by swinging from the Moon, far to the south at the time, toward Albireo, the beautiful bicolored double star halfway across the sky in Cygnus. After I selected it from "Tonight's Suggested Objects," directional arrows appeared, showing the way. Grabbing the mirror-end of the tube, I pivoted the scope's aim. Sure enough, after the bull's-eye on the screen changed from red to green, signaling acquisition, I peered into the 25mm eyepiece and saw Albireo perfectly centered. I was impressed. Pausing for a moment, I selected the "Celestron Audio" feature and listened to a short description of what I had in view. The screen also displayed information about Albireo, including hints on how to best observe it.

Each successive target was also within the 25mm's field of view. Be aware the StarSense may need a moment to catch up if you move the telescope too quickly. A pop-up note will appear at the top of the app's screen advising you that it needs to resync its aim. So, pause and wait for the crosshairs to turn either yellow, meaning that you're close to the selected object, or green, which means you're there.

One night, high clouds began to filter in and thicken. Although I could still see stars through holes in the clouds, the StarSense lost its ability to effectively plate solve the scope's aim. It returned to full functionality without hesitation whenever breaks in the clouds allowed.

Whenever the app is opened, it gives the option to either start immediately, assuming the phone and dock are still aligned from the previous session, or to realign the pair. I found it best to do the latter each time. Typically, when I removed the phone, the cradle slipped a little, since there is no way of locking the dock itself in position.

## An impressive package

Optically, the 130AZ Newtonian scope produced very good results. Images were clear and sharp, allowing me to spot every target I tried — even the "challenge objects" — from my suburban backyard. The tube assembly was accurately collimated out of the box, a saving grace for first timers. Both the center-spotted primary and secondary mirrors can be collimated by the user, if needed.

I came away really impressed with the StarSense Explorer 130AZ. Images were very good and the push-to accuracy was always spot on. I had expected it would get the scope close to a target but require some hunting to actually center it in view. But no — of the dozens of objects I examined, each was within the low-power field every time. That leads me to wonder if Celestron might offer a StarSense dock that could be retrofitted onto existing scopes. I'd certainly buy one.

**Phil Harrington** *is a contributing editor of* Astronomy *with extensive observing experience using telescopes and binoculars.*

# Getting a handle on it

Tour the sky around Ursa Major.

The Pinwheel Galaxy (M101) has magnificent spiral arms and about twice the number of stars as the Milky Way. JARED BOWENS

**BY PHIL HARRINGTON**
*Phil is a longtime contributor to* Astronomy *and the author of many books.*

Undoubtedly, one of the first patterns in the sky that you and I learned as we got into stargazing was the Big Dipper. Its seven stars form a distinctive shape that catches the eye of anyone living in the Northern Hemisphere.

May brings the Dipper high in our early evening sky, so let's take this opportunity to become acquainted with some binocular treasures that lie nearby.

We'll begin with the middle star in the Dipper's handle, **Mizar** (Zeta [ζ] Ursae Majoris). Shining at 2nd magnitude, Mizar is a white-hot spectral type A star lying about 83 light-years away.

Even without binoculars, you might be able to see that it has a friend: a 4th-magnitude point to its northeast. That's **Alcor** (80 Ursae Majoris), also a type A star. They appear separated by about 12', within range of naked-eye resolution if light pollution permits. Modest pocket binoculars will show them easily.

**May brings the Big Dipper high in our early evening sky.**

Alcor and Mizar may well have been your first double star; they were mine. Though there's still some debate on whether these two stars constitute a real binary or simply a visual binary, you can certainly enjoy the view either through binoculars or, if you're lucky enough, with your eyes.

Notice the 6th-magnitude star 1.5° east of Mizar; this star, along with three other similar stars, forms an equally spaced line of four that slides southeastward towards our next target. Tuck Mizar into the northwest corner of the field. Then, without shifting your binoculars' aim, let your eyes zig from Mizar along that line, then zag 1.5° east of its last star. That should put you almost square on the **Pinwheel Galaxy** (M101).

Images of M101 show a grand design face-on spiral, with magnificent arms wrapped around a brilliant nucleus. Remember those images as you strain to see even the faintest hint of its existence. The contrast between M101 and the surrounding sky is so slight that distinguishing its feeble glow is challenging. Even Charles Messier described it as "very obscure and pretty large." You'll stand the best chance by bracing your binoculars against a steady support. If you are convinced your aim is correct but still do not see it even with averted vision, try jiggling the binoculars ever so slightly. This technique often reveals an uncooperative object.

If M101 is a little too challenging, try your luck with the **Whirlpool Galaxy** (M51). To find it, shift your view to Alkaid (Eta [η] Ursae Majoris) at the end of the Dipper's handle. I find M51 by placing Alkaid along the northeastern edge of the field and then glancing from it to 4th-magnitude 24 Canum Venaticorum, 2° to its west. From there, I shift my gaze an equal distance to the latter star's southwest, to a rectangle of fainter stars. M51 is inside that rectangle, next to the star at the northeastern corner.

My 10x50 binoculars show M51 as a round, dim glow. But don't just grab a quick glance and move on. Again, brace your binoculars on a tripod or some other support and make a long, slow study of the galaxy. Can you see that M51 is a little lopsided, with a lump protruding on its north side? If so, you've just seen something through your binoculars that Charles Messier himself missed. That's M51's companion galaxy, **NGC 5195**. It glows weakly at about 10th magnitude.

Finally, for double-star fans, let's swing 5°, or about one binocular field, northeast of Alkaid, across the border to Boötes. There, you will find a triangle of stars formed by **Kappa** (κ), **Iota** (ι) and **Theta** (θ) **Boötis**. Iota, the southernmost of the three, pairs a 5th-magnitude spectral type A white main sequence star with an 8th-magnitude type K orange companion lying 38" to the northeast. That's tight, but still resolvable through 7x binoculars. Higher magnifications will have little trouble cleaving the pair.

Questions, comments, suggestions? Contact me through my website, philharrington.net. Until next time, remember that two eyes are better than one.

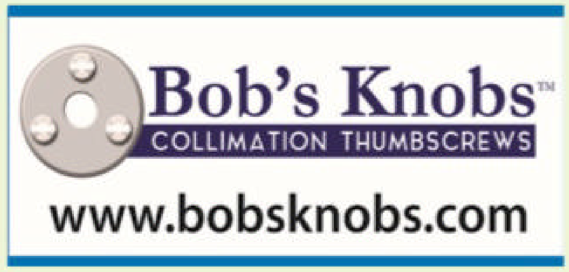
BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT **www.Astronomy.com/Harrington**

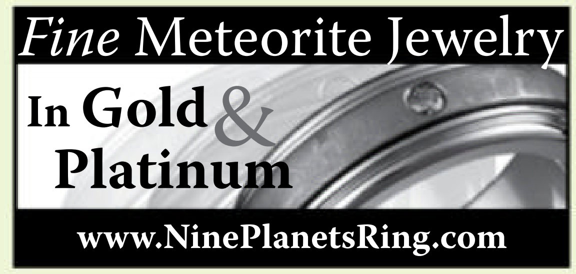
# INDEX *of* ADVERTISERS



The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.














MARKETPLACE

# Observing from your backyard

Equipment is important. Easy access is key.

Sometimes the best observing site is right in your backyard. Here, the author's scope is set up in the center of a network of paths shoveled in the snow. This makes it exceptionally easy to both access stored equipment and take quick breaks to warm up in the house. GLENN CHAPLE

If you're an avid backyard astronomer and own a scope, I have a question for you: What's your home setup like?

Let's say that you're fortunate enough to live where 6th- or 7th-magnitude stars are visible on a clear, moonless night, and your horizon is wide open in all directions. You own a large, fancy, computer-controlled telescope, as well as all the necessary accessories to capture astroimages worthy of *Astronomy*'s Reader Gallery section. For you, having some kind of permanent structure is a necessity — unless you don't mind wasting precious time lugging your telescope and equipment outside each clear evening. It's impossible to provide detailed instructions for constructing your own backyard observatory in a single column, but if your gear is that sophisticated, it's worth browsing the internet for a few observatory ideas that suit your personal needs.

What about the rest of us, though — yours truly included? We have observatories, too; they're just not as sophisticated as custom-built structures. In the most basic sense, an observatory is nothing more than where you place your scope for an evening of skygazing, whether it's a clear space in your yard or a spot near an open window.

"An open window for an observatory?!" purists will shriek. In the Edmund Scientific publication *All About Telescopes* (I can picture you old-timers smiling with fond memories of that 1960s classic), author Sam Brown noted that window-gazing is something to avoid. For the most part, he was right. Not only will you have to deal with turbulence caused by different indoor and outdoor air temperatures, but you'll also be limited to a small area of sky.

That said, during my earliest telescopic adventures, I eschewed this advice. While in high school, I bought a second-hand telescope: a 40mm tabletop refractor with magnifications varying from 15-60x. It was essentially junk by any standard. But on summer nights, when indoor and outdoor temperatures had equalized, I would slide an end table up to my open bedroom window, put my little scope in place, and aim it towards the Moon or a bright planet.

As primitive as it was, this makeshift observatory worked for me. I might not have been able to spot the Moon's Straight Wall, festoons in Jupiter's cloud belts, or the Cassini division in Saturn's rings, but I was able to behold the Moon's cratered surface, watch the night-by-night dance of Jupiter's four Galilean moons, and admire Saturn's fabled rings. As basic as they were, these enthralling sights still managed to launch my lifelong interest in astronomy.

A majority of amateur astronomers are in a situation where a permanent observatory isn't practical or necessary. My observatories are select locations on our property, whether on the lawn or the driveway. In any case, your chosen site needs to afford an open view of the sky, be isolated from nearby lights, and avoid overlooking the heated roof of a neighbor's house, which makes the air above it more turbulent. I've always preferred setting up my telescopes on the lawn instead of the driveway, as I feel driveways radiate heat much like neighboring rooftops. However, a number of my astronomer friends commonly observe from their driveways. It works, they say, if you wait long enough after sunset for the pavement to cool down.

Wintertime in northerly latitudes poses another problem for backyard astronomers attempting to set up impromptu observing sites — snow! It's hard to move a telescope from place to place when it means trudging through a foot or two of snow. In my younger days, I'd select several key spots that would allow me to view as much of the sky as possible. At each, I would shovel a 6- to 8-foot square, and then interconnect the individual sites with a number of paths. Two more shoveled corridors allowed access to both the back door of my house and the shed where I store my scope. Nowadays, an aging back means I can only select one or two primo squares to carve out.

**"An open window for an observatory?!" purists will shriek.**

The big advantage to having some kind of observatory on your property — whether mobile or established — is convenience. It's much easier to take a short walk to your telescope than it is to pack everything in your car and drive off to a remote observing site (especially if you discover that you left your eyepieces at home). But what happens when conditions where you live — overwhelming light pollution, a totally obstructed horizon, or unfortunate latitudinal location — make backyard skygazing impractical? Stay tuned!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Choosing a remote observing site. Clear skies!

**BY GLENN CHAPLE**
*Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.*

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple**

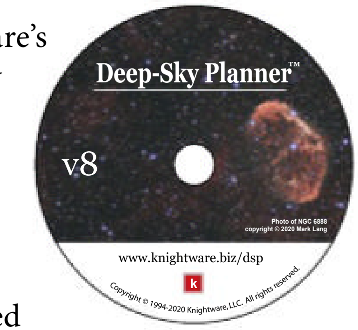

*Attention, manufacturers: To submit a product for this page, email* **products@astronomy.com**.

## Night-vision eyepiece
**OVNI Night Vision**
France

The OVNI-M line of eyepieces by OVNI Night Vision is designed specifically for astronomy. Thanks to white phosphor tube technology, these eyepieces present a natural-color view. The 1.25-inch-diameter eyepieces can be used to scan the sky conventionally with OVNI's removable 26mm f/1.2 lens or fit directly into a telescope. An included adapter allows you to attach 2" filters as well.

**€6,299.00 (FOM 1800), €6,799.00 (FOM 2100), €8,999.00 (FOM 2400), €10,999 (FOM 2600)**
**joko@ovni-nightvision.com**
**www.ovni-nightvision.com**

## Observing planner
**Knightware**
Cary, North Carolina




Knightware's Deep-Sky Planner 8 software provides observers with an updated database of more than 1.6 million objects from the most up-to-date peer-reviewed professional catalogs. The software not only allows you to generate and run observing plans, but also offers access to pre-built plans available for download. Deep-Sky Planner 8 is available for Windows 8.1 and 10 via immediate download or CD.

**$75.00 (digital), $85.00 (CD)**
**presales@knightware.biz**
**www.knightware.biz**

## On-the-go pier
**Harrison Telescopes**
Wilmington, United Kingdom

Harrison's Altair Tri-Pier is a compact, portable pier for on-the-go imaging. It comes with a removable top adaptor and is compatible with 10 mounts: EQ3, EQ5, AZ4, EQM35, HEQ5, AZEQ5GT, AVX, Vixen GP, OVL SkyTee 2, and Altair Sabre. When opened, the pier reaches a height of 3.2 feet (1 meter) and weighs about 19 pounds (8.9 kilograms). The Altair Tri-Pier comes with a custom nylon carrying bag and is available in four colors: red, green, blue, and silver.

**£325.00**
**01322 403407**
**www.harrisontelescopes.co.uk**

At the core of NGC 6357 sits the open cluster Pismis 24. Our own Sun was born within such a cluster 4.6 billion years ago. Since then, it and its stellar siblings have dispersed throughout the galaxy, but astronomers are keen to hunt those siblings down. NASA, ESA AND JESÚS MAÍZ APELLÁNIZ (INSTITUTO DE ASTROFÍSICA DE ANDALUCÍA, SPAIN). ACKNOWLEDGEMENT: DAVIDE DE MARTIN (ESA/HUBBLE)

# The hunt for solar siblings

**Q** | WHAT HAPPENED TO THE SUN'S ORIGINAL STAR CLUSTER? IS IT POSSIBLE FOR NEW CLUSTERS TO FORM FROM RANDOM STARS BEING GRAVITATIONALLY ATTRACTED TO EACH OTHER?

***Cristine Mincheff***
*Ames, Iowa*

**A** | Star clusters are held together by a combination of their own gravity and the gravity of the gas out of which they form. At the end of the star-formation process, the gas is dispersed and the gravity of the stars alone usually isn't enough to hold the cluster together any longer. So, only a small minority of clusters manage to survive the dispersal of their parent gas cloud. Some of these are later pulled apart by the tidal forces exerted by other nearby clouds. For others, over a very long time, individual stars are cast out from the cluster due to random close encounters between the stars. And all of these processes are a one-way street: Once stars leave a cluster, they are moving too fast to be recaptured.

Every kind of star cluster experiences these processes to some degree, but not equally. Globular clusters, for example, are massive old clusters that form differently than smaller, younger open clusters. In globular clusters, random encounters between stars have removed only a tiny fraction of their population over age of the universe. Small open clusters, like the Sun's parent cluster, are much more vulnerable.

We still can't say exactly which process was responsible for dissolving the Sun's parent cluster, or even exactly where in the galaxy the cluster formed. The Sun is 4.6 billion years old. Over that time, the galactic disk has completed more than 20 rotations, so the Sun and the stars with which it was born have had lots of time to wander around and disperse. However, astronomers are hunting for siblings of our star by looking for chemical compositions that match our Sun — almost like a stellar fingerprint. They made the first discovery of a solar sibling, HD 162826, in 2014 and a likely second sibling, HD 186302, in 2018. There's likely to be a few thousand more siblings hidden throughout the Milky Way — it's just a matter of tracking them down.

***Mark Krumholz***
*Astrophysicist, Australian National University, Canberra, Australia*

**Q** | IF YOU WERE ON VENUS AND LOOKING AT EARTH, WHAT FEATURES WOULD YOU BE ABLE TO SEE WITH OUR MODERN-DAY TELESCOPES (PROFESSIONAL AND AMATEUR)?

***Jeff Hemperly***
*Massillon, Ohio*

**A** | The best time for a venusian astronomer to look at Earth would be when our planet is opposite the Sun as seen from Venus, which last occurred in June 2020. This is called opposition. Amateur astronomers may remember the nice views we had of Mars' surface features in October 2020, when the Red Planet was at opposition. For any hypothetical observers on Venus, Earth at opposition would appear almost three times

as large as Mars did from Earth, creating even better views. From Venus, even small amateur telescopes would have been able to easily distinguish continents, oceans, polar ice caps, and shapes of large land masses like Greenland and Australia. Larger telescopes could see even more detail.

Of course, that's assuming that these telescopes aren't enveloped in Venus' thick atmosphere. Not only would it block their view of the sky, its crushing pressure would also destroy any telescopes. So instead of being on the surface of Venus, let's say that the telescopes are in orbit. If the Hubble Space Telescope was orbiting Venus, venusian astronomers would be able to distinguish the Big Island of Hawaii very easily.

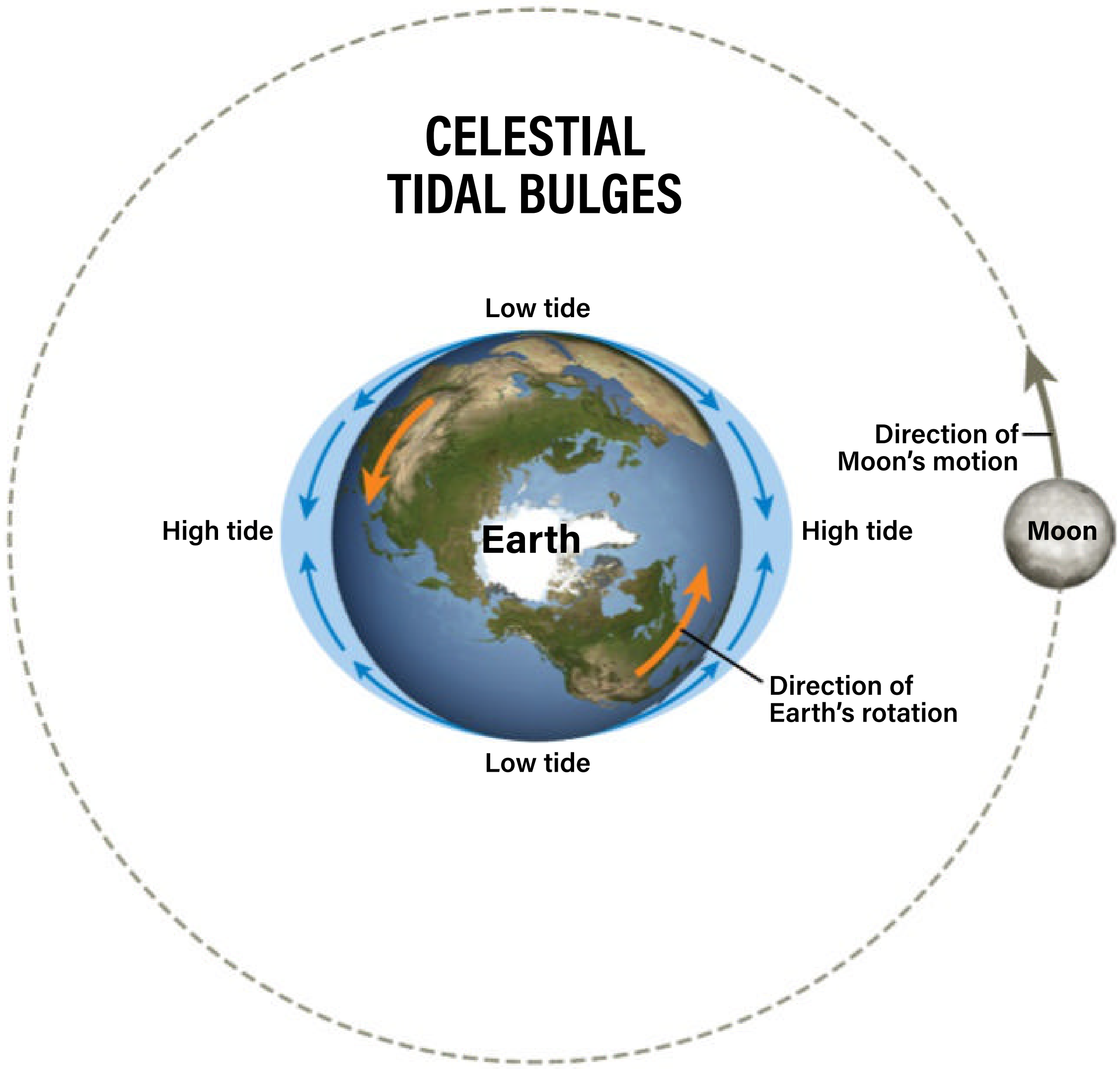
Now let's say there are amateur space telescopes above the atmosphere at Venus. A 4-inch space telescope would only distinguish features on Earth much larger than Hawaii, and even an 8-inch space telescope would not quite make out the Big Island. A 24-inch space telescope, on the other hand, would see Hawaii as a nice dot. All of them would see gorgeous views of Earth's larger features. But although these telescopes are above the clouds of Venus, they would still have to contend with the clouds on Earth blocking those views, just as when we try to look at Venus from Earth.

***Kelly Fast***
*Near-Earth Object Observations Program Manager, Planetary Defense Coordination Office, NASA Headquarters, Washington, D.C.*

**Q** | ARE THE ICE GIANTS (OR ANY SOLAR SYSTEM PLANETS) STILL MIGRATING IN THEIR ORBITS, THE WAY THE MOON ORBITS EARTH FROM SLIGHTLY FARTHER AWAY EACH YEAR?

***Glen Hicks***
*Monument, Colorado*

This view of Earth and the Moon was captured from Mars by NASA's Reconnaissance Orbiter. Venus is about two times farther from our planet than Mars is, but hypothetical venusian astronomers would still be able to see our planet's continents, oceans, and polar ice caps. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA




The Moon's gravity pulls the ocean closest to it slightly farther out than the rest of Earth. On the opposite side of the planet, the ocean feels less gravitational force and bulges outward as the rest of Earth is pulled toward the Moon. ASTRONOMY: ROEN KELLY

**A** | The ice giants are migrating very little, and any migration that they undergo is certainly not for the same reason that Earth's Moon is moving away from us. Many factors affect orbits of large bodies, which are actively fluctuating, if slightly. But two key factors are tidal interactions and the distance between the two bodies.

Earth's gravity keeps the Moon in orbit around us and the Moon in turn causes the oceans' tides. The side of Earth that faces the Moon feels a bit more gravity, while the side facing away feels less, creating a slightly oblong Earth. Called tidal bulges, these oblong areas can occur on solid ground, but are most noticeable in the ocean. Earth's rotation means that the tidal bulge facing the Moon will always be just ahead of the Moon, pulling our natural satellite forward. This gives the Moon a gravitational boost, pushing it farther away.

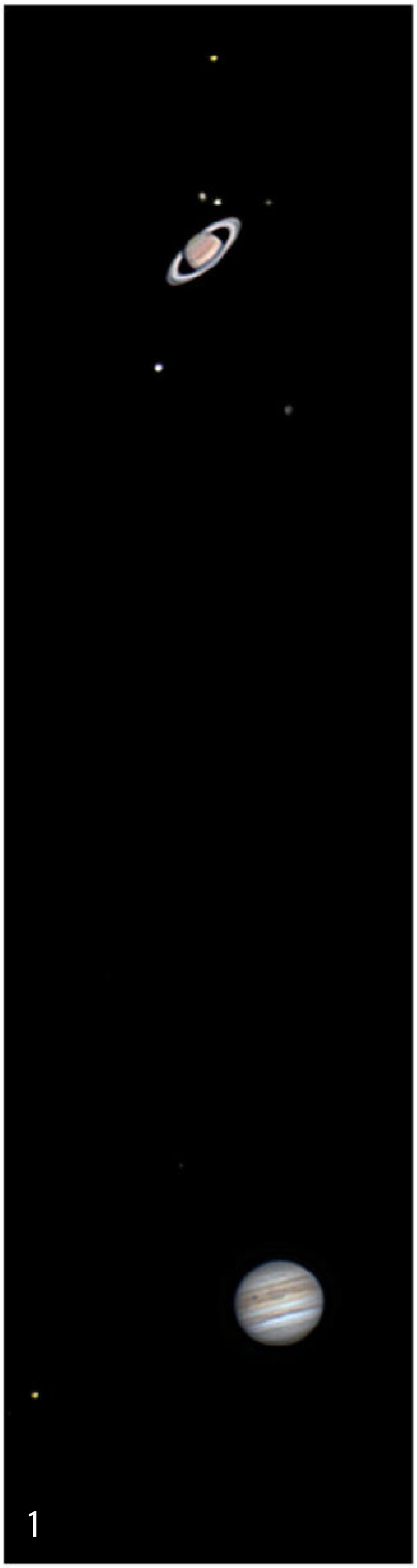
But the Moon is only 60 Earth radii from us, whereas Uranus is 4,000 or so solar radii from the Sun. So, the tidal influence of the Sun on Uranus' orbit is smaller by around 16 orders of magnitude (that's a factor of $10^{16}$). The effect for Earth or even Mercury is much larger but still negligible. It is likely, however, that Mercury's and Venus' spins experienced some tidal influence, slowing their rotation somewhat since they were first formed.

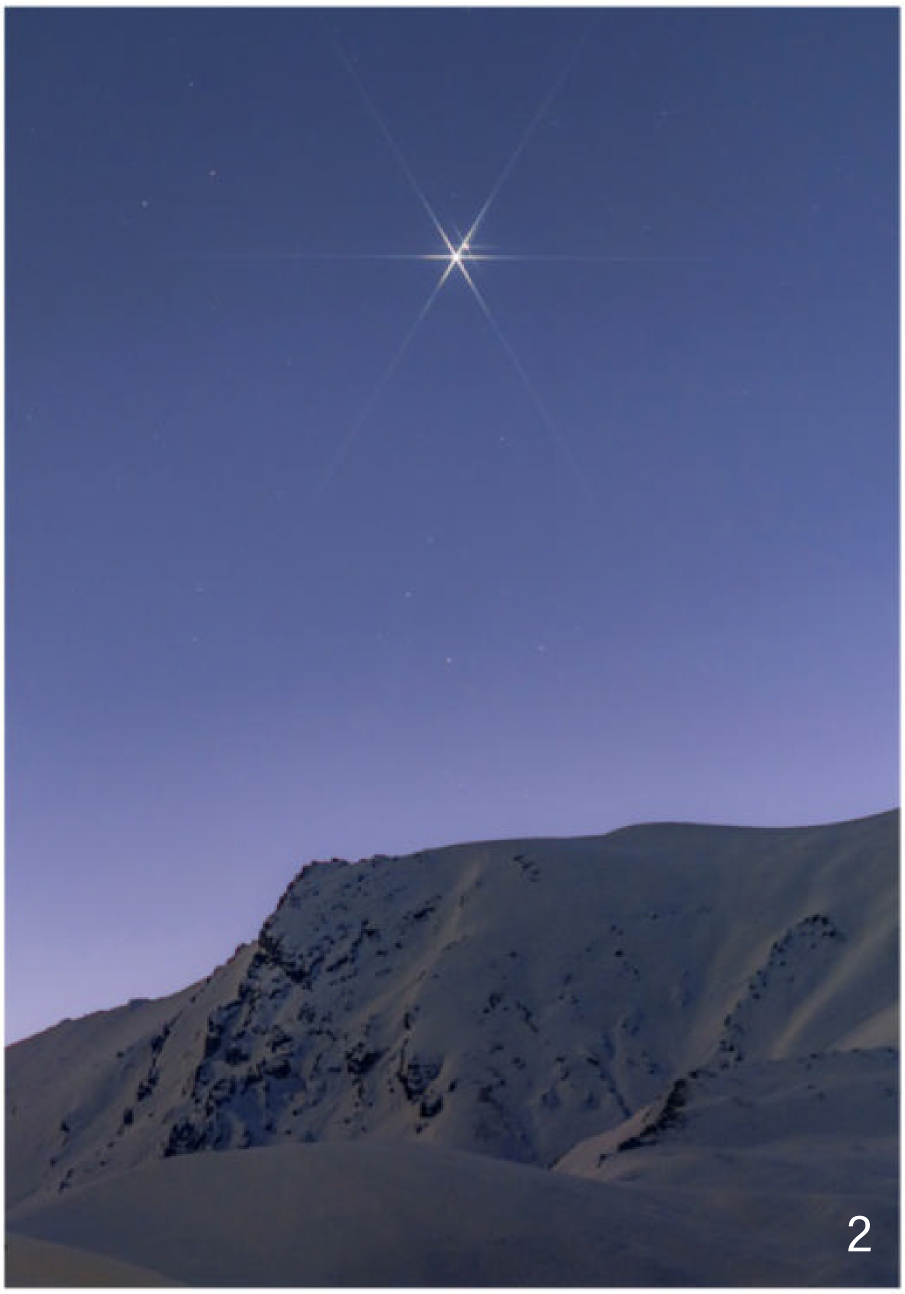
***David Stevenson***
*Professor of Planetary Science, Caltech, Pasadena, California*

## SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

# Cosmic portraits


1


2

**1. CLOSE ENCOUNTER**
Conjunctions of Jupiter and Saturn — known as "great conjunctions" — occur about every 20 years. As the timing of the most recent such event coincided with 2020's winter solstice, it also received the popular moniker "Christmas star." This composite of the two planets and their moons was taken from Mazatlán, Mexico, on the evening of Dec. 21, 2020, with the planets near their minimum separation of 6'.
*• René Saade*

**2. RARIFIED AIR**
Jupiter and Saturn blazed above the Alborz Mountains north of Tehran, Iran, on Dec. 21, 2020. This exposure was 2.5 seconds and taken with a star cross filter.
*• Amirreza Kamkar*

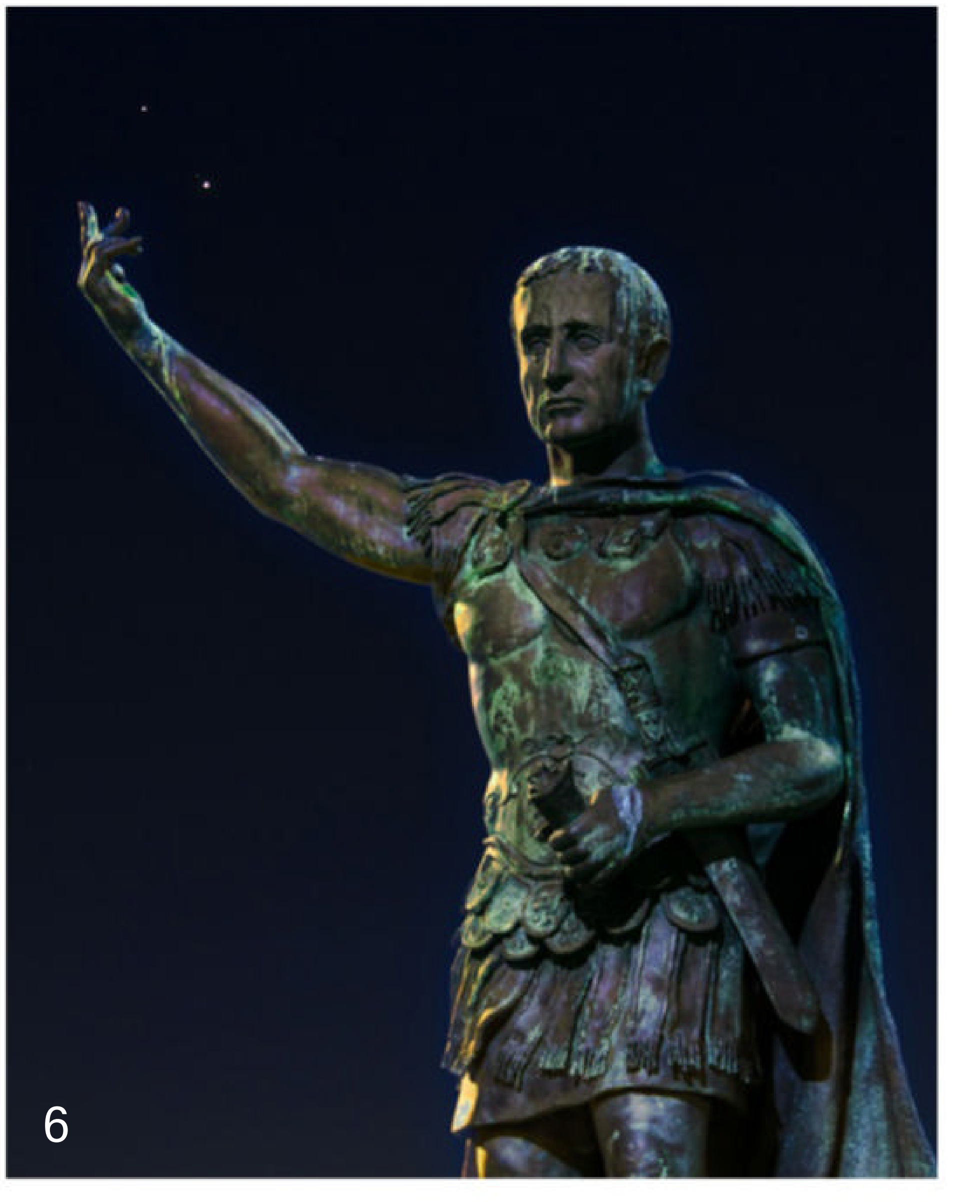
**3. MAKING MEMORIES**
A young astronomer views Jupiter and Saturn's conjunction over the Atlantic Ocean from Chatham, Massachusetts, on Cape Cod. The half-second exposure was taken with an iPhone 11 Pro on Dec. 22, 2020.
*• Chris Cook*


3

**4. ROSES ARE BLUE**
The Rosette Nebula is a gorgeous cloud of ionized gas in Monoceros that surrounds the open cluster NGC 2244 and glows at magnitude 9.0. This image was captured over 90 exposures totaling 75 minutes, with filters similar to the ones used by the Hubble Space Telescope. • ***Andrew Alvey***

**5. WARM GLOW**
The Moon joins Jupiter and Saturn in this scene from Cedar Rapids, Iowa, on the evening of Dec. 16, 2020. The image is a five-second exposure at f/9 and ISO 250. • ***Gregg Alliss***

**6. IMPERIAL REACH**
"The more you tighten your grip, Trajan, the more planets will slip through your fingers": This statue of the Roman emperor Trajan appears to hold Jupiter and Saturn in his hand as they neared conjunction on Dec. 13, 2020, over the Italian port of Civitavecchia. • ***Marco Meniero***



**7. GOT FISH?**
The Dolphin Nebula (Sharpless 2–308) is the wind-blown bubble of a central, massive Wolf-Rayet star, the bright blue star in the lower-center of the frame. The photographer combined 36 hours of exposure time using a 14-inch scope.
***▪ Fred Hermann***

**8. BUBBLING CAVES**
This five-image narrowband mosaic spans over 4° and reveals a vast region of nebulosity in Cassiopeia and Cepheus. The gaping maw of the Cave Nebula is the large feature in the lower left quadrant; to its upper left lies the Bubble Nebula and, at the side of the frame, the open cluster M52. ***▪ Alistair Symon***

**9. TOUCHING TADPOLES**
The emerald-green Comet C/2020 M3 (ATLAS) passed through the constellation Auriga and nearly grazed the Tadpoles Nebula (IC 410) in the lower left of this image from Dec. 10, 2020. The Flaming Star Nebula (IC 405) is the comma-shaped emission and reflection nebula just right of center. ***▪ Terry Hancock/ Tom Masterson/Grand Mesa Observatory***

**10. IN A HURRY**
NGC 3981 is a spiral galaxy in the constellation Crater that shines at magnitude 11.8. Though its arms look as if they're trailing in the breeze, they consist of stars that were ripped outward by past collisions with other galaxies. ***▪ Adam Block/ Telescope Live***


7


9


8

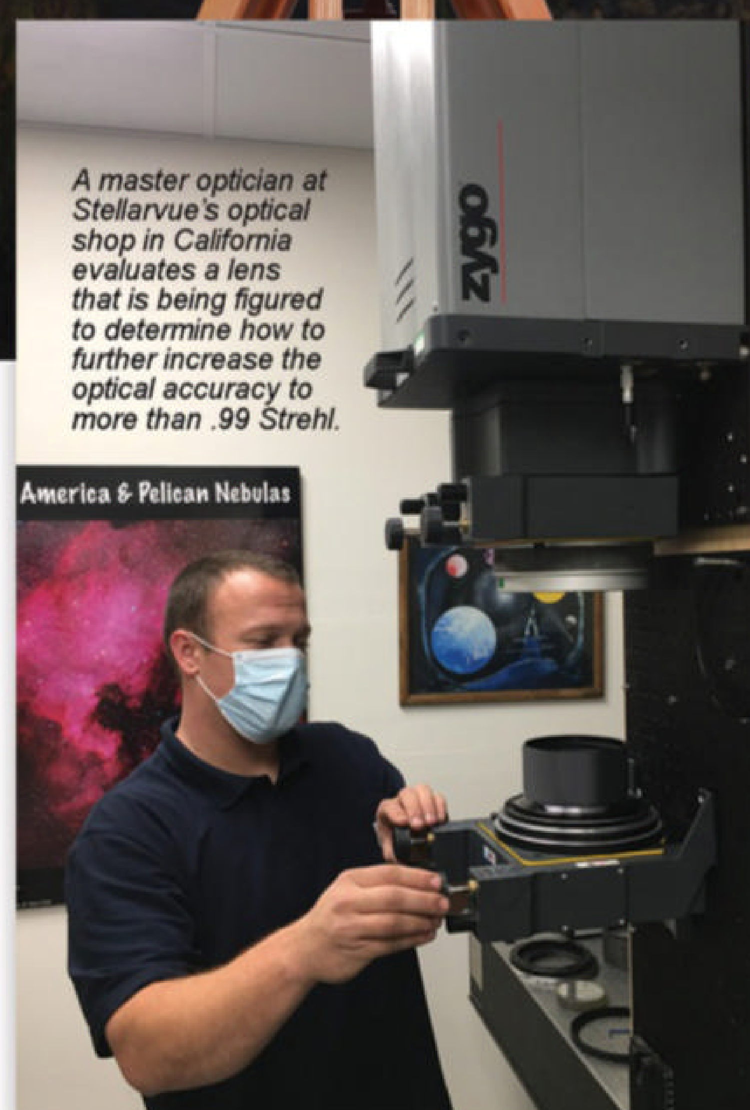
**SEND YOUR IMAGES TO:**
*Astronomy* Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@ astronomy.com.**

## A STUNNING PRIDE OF GALAXIES

While British astronomer Ralph Copeland was scouring northeastern Leo the Lion in April 1874, he stumbled upon a compact group of seven indistinct objects. In the nearly 150 years since, astronomers have learned that Copeland's Septet is a group of eight interacting galaxies (one was too faint for Copeland to see) residing 400 million light-years from Earth. The brightest member, spiral galaxy NGC 3753, lies just left of center and features a warped disk as well as a long stream of stars that its neighbors have torn from it. Scientists took this portrait with the 4-meter Victor M. Blanco Telescope on Cerro Tololo in Chile as part of the DESI Legacy Imaging Surveys, which captured more than 1 billion galaxies across half the sky.

DESI LEGACY IMAGING SURVEYS/LBNL/DOE & KPNO/CTIO/NOIRLAB/NSF/AURA


STELLARVUE
OWN THE NIGHT
STELLARVUE
SVX102D Apo
on the M002CW
Mount & Tripod
STELLARVUE
Super-Planetary
127mm f-8 Apo
on the M002CW
Mount & Tripod


A master optician at Stellarvue's optical shop in California evaluates a lens that is being figured to determine how to further increase the optical accuracy to more than .99 Strehl.
zygo
America & Pelican Nebulas

# July 2021
# Venus and Mars come together

Anyone who enjoys watching the planets in motion is in for a treat this month. The evening stage features a dramatic conjunction between the two worlds — Venus and Mars — whose orbits lie closest to Earth's. But July's night sky offers much more for both naked-eye observers and telescope owners, so let's get started.

The first object to emerge during evening twilight is brilliant **Venus**. The planet shines at magnitude –3.9 throughout July and appears like a beacon in the northwest as darkness falls. It grows even more conspicuous as the month progresses because it gains altitude. Venus stands 10° high an hour after sundown July 1; its elevation nearly doubles by month's end.

As Venus moves away from the Sun, it takes dead aim on **Mars**. The two planets begin July 7° apart, but the gap narrows by about 0.5° each day. They are destined for a close conjunction on the 13th, when just 0.5° — the apparent diameter of the Full Moon — separates them. Ruddy Mars glows at magnitude 1.8 to Venus' upper left. A lovely crescent Moon adds to the scene some 10° to the pair's upper right.

A telescope at low power shows both planets in the same field of view. Unfortunately, neither world looks impressive even at higher magnifications. Venus appears 12" across and 87 percent illuminated while Mars displays a featureless disk just 4" in diameter.

Following their conjunction, the two planets continue marching eastward across Leo. Venus moves faster because it orbits closer to the Sun. The inner world passes 1.2° north of 1st-magnitude Regulus, the Lion's brightest star, on July 21. Mars slides 0.7° north of the same star on the 29th.

If you were disappointed in the views of Venus and Mars through your telescope, just wait until Jupiter and Saturn appear later in the evening. **Saturn** rises first, poking above the eastern horizon around 8 P.M. local time in early July and during twilight late in the month. The ringed planet shines at magnitude 0.2 against the dim backdrop of north-central Capricornus. Saturn moves slowly westward relative to this starry background as it approaches opposition and peak visibility in early August.

Don't pass up any opportunity to target Saturn through a telescope. Even the smallest instrument reveals the planet's disk, which measures 18.5" across the equator in mid-July, encircled by a spectacular ring system that spans 42.0" and tips 18° to our line of sight.

**Jupiter** rises about 90 minutes after Saturn along with the stars of its host constellation, Aquarius the Water-bearer. At magnitude –2.7, the giant planet shines nearly 15 times brighter than Saturn and dominates the night sky once Venus sets. Like Saturn, Jupiter is sliding westward relative to the background stars. It will reach opposition in the latter half of August.

A telescope reveals a distinct flattening to Jupiter's disk. In mid-July, the equator spans 46.95", 3.05" more than the polar diameter. The planet's rapid spin and gaseous nature causes this equatorial bulge. Also look for a series of alternating bright zones and darker belts that runs parallel to the gas giant's equator. Jupiter's four bright moons provide an added treat as their relative positions change from night to night and even from hour to hour.

July's final naked-eye planet appears in morning twilight during early July. **Mercury** reaches greatest elongation on the 4th, when it lies 22° west of the Sun and stands 10° high in the east-northeast 45 minutes before sunrise. Shining at magnitude 0.5, the planet makes a fine sight some 10° to the lower right of Aldebaran in Taurus and 15° to the left of Betelgeuse in Orion. A telescope shows Mercury's disk, which measures 8" across and appears about one-third lit.

## The starry sky

I find it fascinating to look at old star charts and discover constellations that no longer exist. Although many of these star patterns lie in the northern sky, one intriguing southern specimen — Turdus Solitarius the Solitaire — passes nearly overhead early on July evenings.

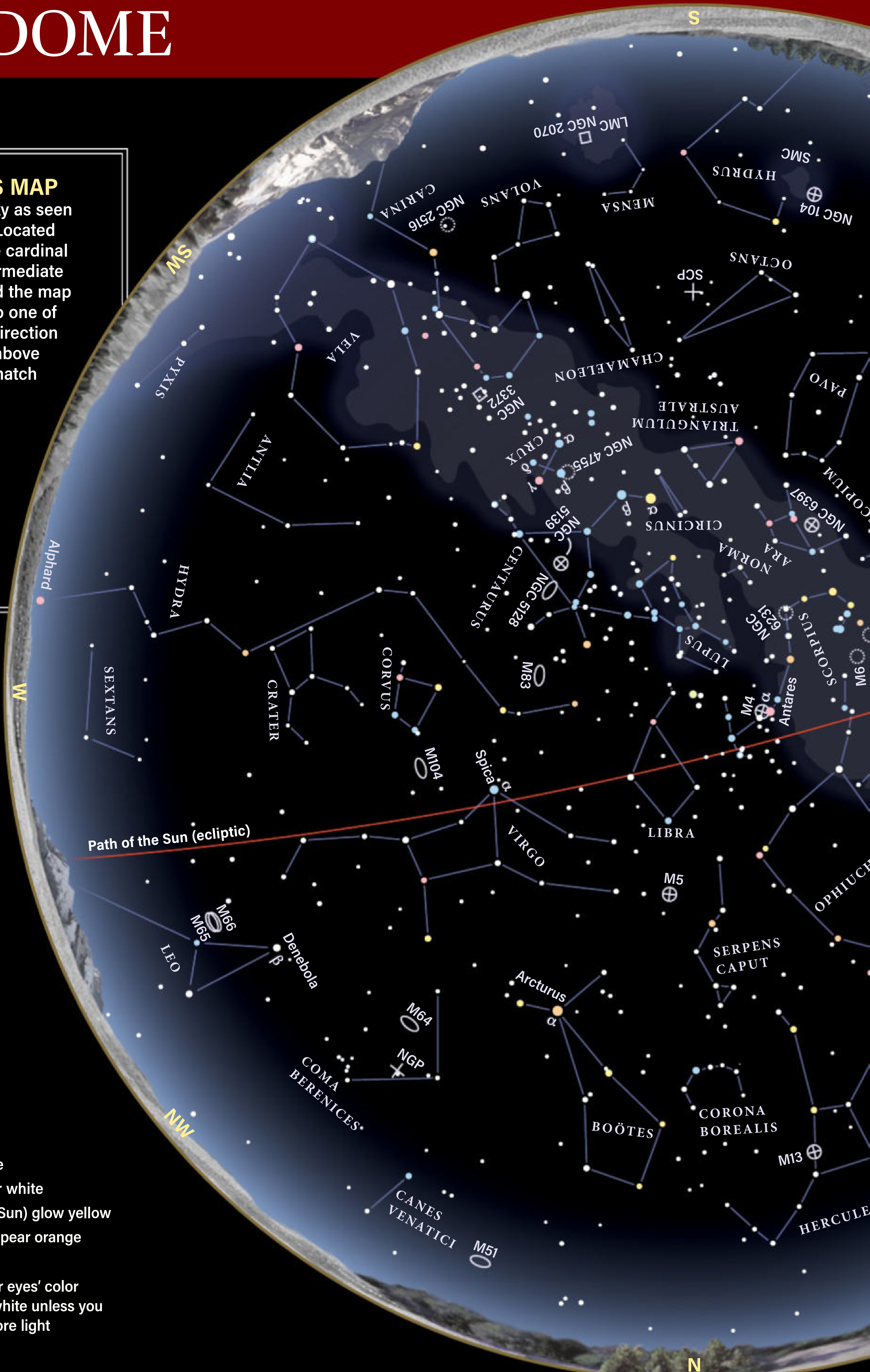
The constellation has nothing to do with playing cards by oneself. The solitaire is a bird, and the obsolete constellation owes its existence to French astronomer Pierre Le Monnier (1715–1799). Writing in 1776, Le Monnier said he introduced the constellation in memory of Alexandre Pingré's (1711–1796) voyage to the island of Rodrigues to observe the transit of Venus.

Strangely, Le Monnier described the bird as being from the "Indies and the Philippines" — the solitaire from the family Turdidae — while Rodrigues is a volcanic island in the Indian Ocean. It's an entirely different bird from the Rodrigues solitaire!

Le Monnier's bird appears upside down to us, perched on Hydra's tail east of the 3rd-magnitude star Pi (π) Hydrae. The star we now call Sigma (σ) Librae marked the bird's chest, and a short line of three 5th- and 6th-magnitude stars a few degrees west and a bit south of Alpha [α] Lib marked its tail. See if you can spot them in binoculars.

Le Monnier was an accomplished astronomer. Had he been more methodical in some of his observations, he might have discovered Uranus. After William Herschel (1738–1822) discovered the seventh planet, a search for earlier observations showed that Le Monnier had recorded the planet many times without recognizing it for what it was.

# STAR DOME




## HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. July 1
8 P.M. July 15
7 P.M. July 31

Planets are shown at midmonth

## MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

## STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

## STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**


# JULY 2021

| SUN. | MON. | TUES. | WED. | THURS. | FRI. | SAT. |
|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 |
| 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 25 | 26 | 27 | 28 | 29 | 30 | 31 |

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

**Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.**

## CALENDAR OF EVENTS

**1** Last Quarter Moon occurs at 21h11m UT

**4** The Moon passes 2° south of Uranus, 15h UT

Mercury is at greatest western elongation (22°), 20h UT

**5** The Moon is at apogee (405,341 kilometers from Earth), 14h47m UT

Earth is at aphelion (152.1 million miles from the Sun), 22h UT

**8** The Moon passes 4° north of Mercury, 5h UT

**10** New Moon occurs at 1h17m UT

**12** The Moon passes 3° north of Venus, 9h UT

The Moon passes 4° north of Mars, 10h UT

**13** Mars is at aphelion (249.2 million miles from the Sun), 0h UT

Venus passes 0.5° north of Mars, 7h UT

**17** First Quarter Moon occurs at 10h11m UT

Asteroid Hebe is at opposition, 11h UT

Pluto is at opposition, 23h UT

**18** Asteroid Pallas is stationary, 20h UT

**21** The Moon is at perigee (364,520 kilometers from Earth), 10h24m UT

Venus passes 1.2° north of Regulus, 19h UT

**24** Full Moon occurs at 2h37m UT

The Moon passes 4° south of Saturn, 17h UT

**26** The Moon passes 4° south of Jupiter, 1h UT

**27** The Moon passes 4° south of Neptune, 18h UT

**29** Mars passes 0.7° north of Regulus, 16h UT

**30** Southern Delta Aquariid meteor shower peaks

Asteroid Victoria is at opposition, 13h UT

**31** Last Quarter Moon occurs at 13h16m UT